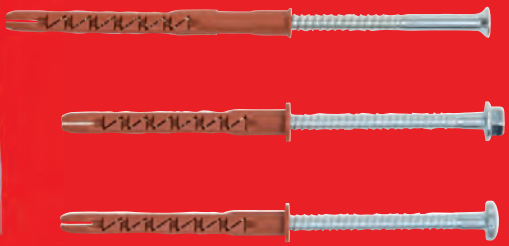
MINITHEK metallmarkt volume 10

Anchor technology

– concentrated and consolidated



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Anchor technology

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A solid base

The modern metalworking business has to accomplish manifold tasks. Anchor technology plays a central and connecting role in this field. Facades, sun protection, stairs or railings: Safe, flexible, and economic fastenings are needed everywhere. The industrial partners provide a vast number of high-quality and efficient products which cover these applications. We have summarized the basic knowledge of anchor technology in this book.

Being the tradition of the metall-markt.netMINITHEK, this MINI-handbook of anchor technology is available free of charge in the requested quantities for inter-company educational institutions of the metalworking business. This was enabled by our sponsor, the Adolf Würth GmbH & Co. KG. „With our commitment we would like to contribute in imparting the basic knowledge about anchor technology already during education. We would like to empower the reader to use modern anchors in a qualified way. The metall-markt.netMINITHEK is an ideal instrument for this."

Stefan Elgaß
Editor in Chief
www.metall-markt.net

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1. Applications

The essential advantage of post-installed or power-actuated fasteners compared to cast-in-place fasteners is the possibility for installation at an 'almost arbitrary' location in a structural component. No detailed pre-design is necessary and changes in use of a building are realized quickly and simply.
Today it is common construction practice to fix structural and non-structural components to reinforced concrete or masonry structures using post-installed fasteners. New materials in concrete and masonry construction constantly present new challenges to provide connection solutions through the development of innovative fastening systems.
An overview of current post-installed fastening systems for use in concrete and masonry is given in Figure 1.1.

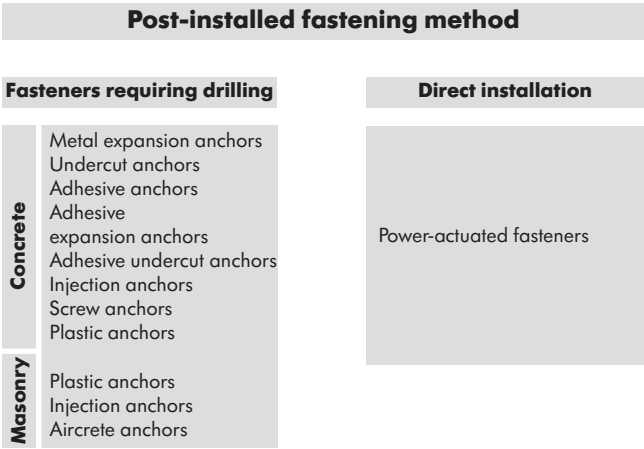


Figure 1.1: Post-installed fastening systems

The diversity of products has increased with the number of possible applications for fastening devices. For the user in the practice it is often difficult to find the correct fastening solution and to design safe connections. For example, as a result of several, in part severe accidents, mainly due to improper use of post-installed fasteners, an approval system for fastening systems was introduced in Germany in 1975. Since uniform test methods and evaluation criteria were used for the approval procedure, the performance of fasteners from different manufacturers could be compared. Furthermore, the conditions of use of the fasteners were defined exactly in the approval document.

The selection of a fastening system should be based on the following questions:
Which type of fastening system is most suitable for the solution of my fastening problem?
The second question is:
How can I utilize the performance of the fastening system in the best possible way?
The answers to these questions are the domain of the planner and the engineer.

The best design method and the most careful design by an engineer, however, are of no use if the fastening device specified by the designer does not function reliably or is not installed properly. The factors influencing the successful design of connections are illustrated in Figure 1.2. Further details concerning the selection of a suitable fastener can be found in chapter 7.

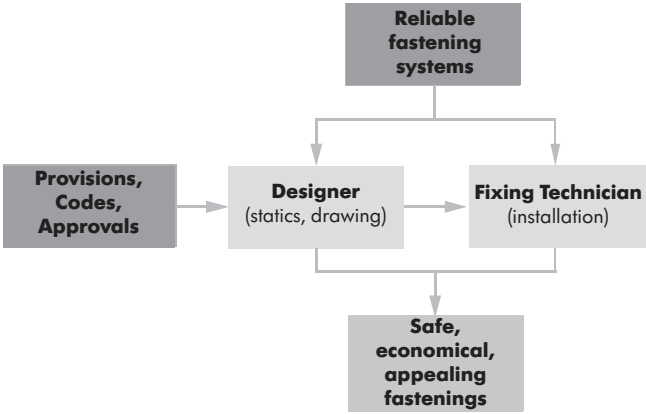


Figure 1.2: Success factors for safe fastening with post-installed fasteners [1]

It goes without saying that fasteners which are intended to transfer high loads and used in safety-relevant applications should be designed by experienced personnel. Reproducible computations and drawings must be generated. The installation should be performed by trained and experienced workers, if possible by 'Certified Fixing Technicians'.
Reliable connections, based on reliable fasteners and appropriate design procedures, can only be ensured by cooperation of both the designer and the installer. Some examples from the wide range of applications for fastening systems are shown in Figures 1.3 and 1.4. One should never lose sight of the fact that proper connection design and application are vital for the overall performance of a structure.

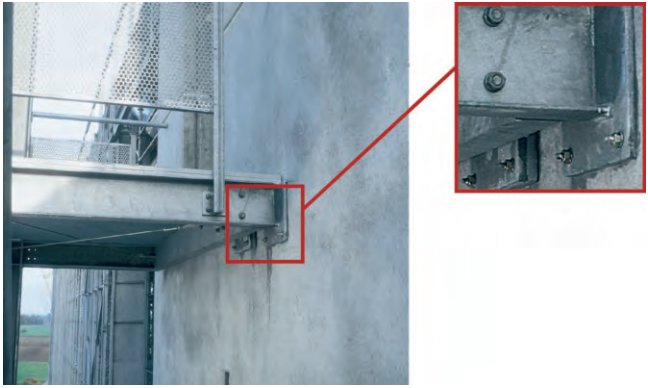


Figure 1.3: Fastening of a steel member with the Würth W-FAZ/A4, M16

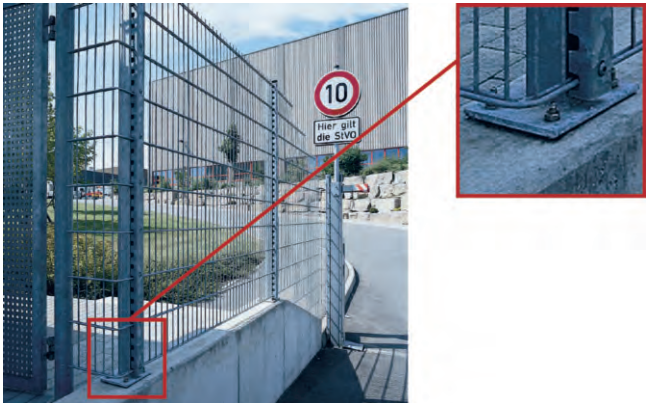


Figure 1.4: Fastening of a fence with the Würth W-VIZ/A4, M12

2. Base material

2.1 General

Construction materials can be solid, porous, extremely hard, extremely soft, weathered, or new, i.e. they have significant differences in density and strength. The type and structure of the base material significantly influences the selection of the fastening system and its load-bearing behaviour.
Typically, concrete, masonry, and soft materials such as autoclaved aerated concrete serve as base material for fasteners (Figure 2.1). Masonry can consist of solid, perforated, or hollow units.

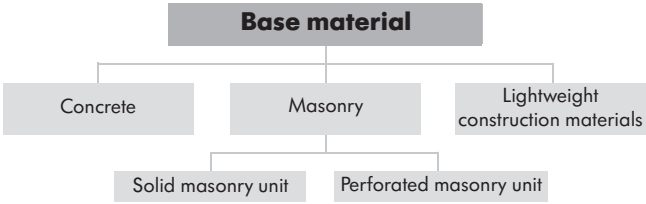


Figure 2.1: Base materials

2.2 Concrete

2.2.1 General

Concrete is a mineral-based construction material. It is typically produced from a mixture of cement and water, which serves as binding material, and a combination of sand as well as fine and coarse aggregates. It is mixed shortly before it is poured into the shape-giving formwork. As long as the concrete can be processed, it is designated as fresh concrete. During the hardening process (hydration), it is called 'young concrete' (age of 1 day to 4 days). After the solidification and

hardening of the cement paste the concrete becomes solid (hardened) concrete. Hardened concrete has a high compressive strength and a relatively small tensile strength (approximately 10 to 15 per cent of the compressive strength).
Concrete is classified according to different aspects,

- according to density:
- Lightweight concrete – dry density 0,8 to 2,0 kg/cubic decimetre
- Normalweight concrete – dry density 2,0 to 2,6 kg/cubic decimetre
- High density concrete – dry density above 2,6 kg/cubic decimetre

In general, in normal building construction normalweight concrete is used.

- according to production:
- On-site mixed concrete
- Ready-mixed concrete

Due to economic reasons and aspects of the quality control, ready-mixed concrete is typically used on smaller building sites.

Various concrete characteristics may be achieved depending on the strength of the cement, the characteristics of the aggregates (gravel, grit, crushed gravel), and the quality of the water, as well as the mixture proportions of cement, water, and aggregates.

2.2.2 Concrete proportions

2.2.2.1 Cement

In Europe, today almost exclusively cement according to national or European standards is used for concrete production. The selection of the cement type governs for example the hardening process and the resistance of the concrete to chemical or environmental attacks. For reinforced concrete buildings CEM I (Portland cement) and CEM II (Portland composite-cement) are frequently applied. Cement produced according to a European standard is made in the strength clas-

ses 32,5R, 32,5, 42,5R, 42,5, 52,5R, and 52,5. The numbers represent the strength according to standards in N/mm² after 28 days of hardening. The letter R designates rapid hardening. A higher strength class of the cement indicates a higher final strength of the concrete.

2.2.2.2 Concrete aggregates

Aggregates for normalweight concrete consist mainly of natural materials such as gravel from river deposits or crushed rock. For lightweight concrete pumice stone is often used. In high density concrete artificial aggregates such as iron spheres are used in addition to the granular material for normalweight concrete.
The aggregate significantly determines the workability and strength of the concrete. By means of a suitable graduation of different aggregate sizes, a dense packing of the gravel with few cavities for the cement paste can be realized.

2.2.3 Water/cement ratio

The water/cement (w/c) ratio is the decisive parameter for the concrete quality. It gives the ratio of water to cement in a concrete mixture. The water/cement ratio governs the strength and resistance of the hardened concrete.
The increase of the amount of water yields a more workable concrete. On the other hand, it leads to an increased number of voids in the hardened cement paste and a reduction in concrete strength.
During hardening of the cement paste, an amount of water equal to approximately 40 % of the cement weight is chemically bound (w/c = 0,4). However, for sufficient workability of the fresh concrete a larger water amount is usually necessary. The water that is not chemically bound during hardening does not remain in the concrete. After the excess water has left, voids remain in the concrete and the volume of the concrete is reduced (concrete shrinkage). This causes the reduction in strength of the hardened concrete with increasing w/c ratio. W/c-ratios between 0,5 and 0,6 provide a practical compromise to ensure a sufficiently strong and durable concrete while maintaining the work-

ability of the fresh concrete. Concrete admixtures such as fly ash and silica fume, and additives such as accelerators to increase the rate of hydration, or water-reducers to limit the amount of water can be used to achieve the designed workability and strength of the concrete without increasing the w/c ratio.

2.2.4 Concrete strenght

Concrete is classified in European standards according to its concrete compressive strength. With increasing hardening time the concrete

Strength class	$f_{ck,cyl}$ [N/mm²]	$f_{ck,cube}$ [N/mm²]
C8/10	8	10
C12/15	12	15
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C35/45	35	45
C40/50	40	50
C45/55	45	55
C50/60	50	60
C55/67	55	67
C60/75	60	75
C70/85	70	85
C80/95	80	95
C90/105[1)]	90	105
C100/115[1)]	100	115

[1)] C90/105 and C100/115 are high-performance concretes where special requirements have to be fulfilled.

Table 2.1: Concrete strength classes according to EN 206

compressive strength rises. However, the hardening process (hydration) is nearly completed after 28 days. According to the current standards, concrete compressive strength is measured either on cubes with a side length of 150 mm or on cylinders with a diameter of 150 mm and a height of 300 mm in a concrete age of 28 days. In Table 2.1 the most common concrete strength classes are summarized. Obviously, the concrete compressive strength depends on the type of test specimen. The cylinder gives a slightly smaller strength than the cube. Sometimes in practice test specimens with other geometries are used. Conversion factors must be used to convert the strength obtained with these special test specimens to values comparable to those from standard specimens.
The European approvals for fastening systems indicate resistance values for concrete at an age of at least 28 days. Approvals for the use of bonded and plastic anchors in concrete are valid in general for the strength classes of C12/15 to C50/60. Approvals for mechanical expansion and undercut anchors are valid for strength classes in the range of C20/25 to C50/60. Since fastening systems directly utilize the tensile strength of the concrete for the load transfer into the component and since concrete tensile strength develops more slowly than the concrete compressive strength, fastening systems should not be used in concrete younger than 28 days even if the minimum concrete compression strength required by the approvals is already achieved.

2.2.5 Reinforced concrete

The concrete tensile strength is relatively small with roughly 10 % of the value of the concrete compressive strength. Therefore, in practice unreinforced concrete is very uncommon as structural concrete. In general, for concrete structures and components reinforced concrete is used. The basic concept of reinforced is demonstrated by a beam with two supports at its ends (Figure 2.2). Under the applied loads a concrete compression zone and a concrete tension zone are formed. Without reinforcement (steel bars) the beam would fail if the concrete

tensile strength is exceeded. In a reinforced beam the reinforcement resists the tensile load by bond between steel and concrete after cracks form in the concrete. Under service conditions the crack width in a reinforced concrete component designed according to Eurocode 2 is limited to approximately 0,3 mm. Therefore, it can be assumed that where there is reinforcement, a concrete tensile zone, i.e. a zone with cracked concrete, is present.

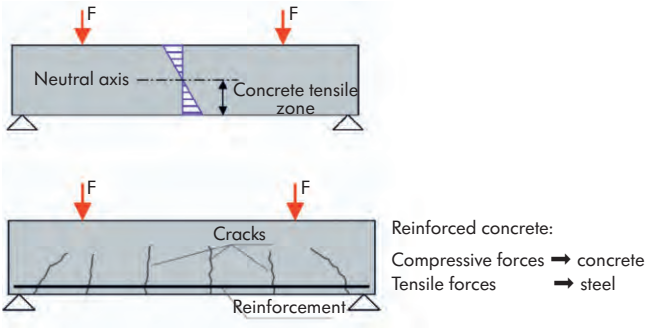


Figure 2.2: Basic concept of reinforced concrete construction

Cracks do not arise, however, only by loading concrete components. They can also be caused at the concrete surface for example by rapid drying, thermal expansion due to cooling and heating (solar radiation), or by settlements of the structure.
Since cracks significantly influence the load-bearing behaviour of fasteners, in fastening technology it is recommended for the design of fastenings in general to assume cracked concrete as the base material.

2.3 Masonry

Masonry is a heterogeneous construction material manufactured from natural or artificial components such as bricks, clay tiles, concrete or limestone blocks stacked with alternating layers of cementitious mortar.

The primary application of masonry is the construction of walls. The placing of the masonry units (e.g. bricks) in a mortar bed ensures an optimal utilization of their compressive strength. The mortar levels the unevenness of the units and ensures a uniform pressure transfer. Masonry generally has a much lower strength than concrete.

Masonry is one of the oldest construction materials used by mankind. Its origins are scattered all over the world. Depending on the local resources, masonry units are manufactured in a wide variety of materials, shapes, sizes, and configurations. Solid units, perforated units, and hollow units with myriad different shapes and void configurations exist.

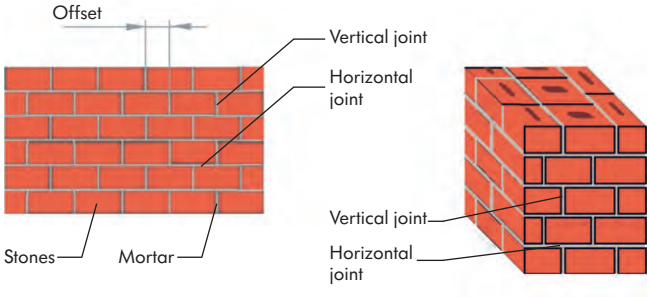


Figure 2.3: Brick-built walls with joints

Moreover, it must be considered that wall plaster or insulation layers are non-load-bearing layers for an anchor. Therefore, the thickness of the non-load-bearing layer always has to be considered with regard to the maximum thickness fastened.
Anchors with high local expansion forces are not suitable for fastenings in masonry. The stones will otherwise already be splitted during installation due to their comparatively small dimensions. This is why systems with low expansion forces like plastic or injection anchors are used in these cases.

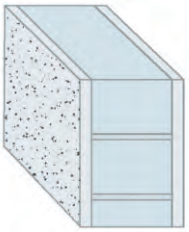


Figure 2.4: Brick-built wall with external and internal plaster

Figure 2.5: Poroton S11 with CE marking according to EN 771

2.3.1 Natural stones

Structure and strength of natural stones vary enormously. This is why there are no existing approvals for the use of anchors in walls made from natural stones. However, if it is necessary to post-install fastenings in masonry made from natural stones the load-bearing behaviour of the fastening has to be determined with pull-out tests and the allowable load has to be deducted by a surveyor.

2.3.2 Artificial stones

Stones exist in a large variety of forms and are classified by a CE marking according to EN 771. In European technical approvals CE marked stones according to EN 771 can be integrated (Figure 2.5). If such stones are checked in the course of an approval procedure the approval documents can include loads for these stones.

The raw densitiy of the stones is approximately between 0,4 kg/dm^3 and 2,0 kg/dm^3. High compressive strengths can in general only be achieved for stones with high raw density. In contrast, good thermal insulation qualities and a small stone weight for better workability can only be achieved with a low raw density. These stones show, on the other hand, a smaller heat storage capacity and worse sound insulation features.

Solid bricks are moulded out of clay or silt and then fired at temperatures between approximately 800 °C and 1000 °C. The firing process influences the features of the stones.

Limestones and concrete masonry units are hydraulically bonded by binding material. They are made of lime respectively cement as binding material, water, and various aggregates (e.g. sand) by pressing or steam curing.

European standardization
EN 771
Part 1: Solid bricks Part 2: Limestones Part 3: Concrete masonry units Part 4: Aerated concrete

Table 2.2: Parts of EN 771

2.3.2.1 Solid bricks

Stones with a reduced profile due to e.g. a grip opening (maximum 15 % for clay masonry units or sand-lime solid bricks – Figure 2.7 – respectively 10 % for concrete masonry units) are called solid bricks. They can be fired (e.g. solid clay bricks) or hydraulically bonded (e.g. sand-lime solid bricks) or solid blocks. Moreover, there is autoclaved aerated concrete as high precision units and blocks. They are made of cement, lime, finest aggregates, and aluminium by steam curing and adding water as propellant.

Masonry with e.g. very high densities or high sound insulation is made of solid bricks. However, the main focus of solid masonry units made from aerated concrete is high thermal insulation. Raw density and strength are respectively low.

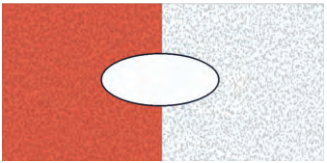


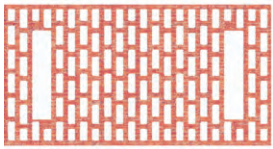
Figure 2.7: Solid brick with grip opening, solid brick on the left, sand-lime solid brick on the right

2.3.2.2 Perforated bricks

Stones with a reduced profile due to openings (more than 15 % for clay masonry units or limestones respectively 10 % for concrete masonry units) are called perforated bricks. These openings can exist in the most diverse shapes and can be spread arbitrarily across the stone.

Fired perforated bricks are, among others, vertically perforated clay bricks (Figure 2.8a). Hydraulically bonded perforated bricks are e.g. sand-lime perforated bricks (Figure 2.8b) or perforated masonry made from lightweight concrete (distinction by the number of chambers).

There are numerous variations apart from the stones already mentioned which are primarily optimized regarding thermal insulation and approved and/or CE marked.



a) Vertically perforated clay brick

b) Sand-lime perforated brick

Figure 2.8: Perforated bricks

3. Actions

Fastening systems must be chosen such that they fulfil the requirements for their application. They must be suitable for the intended use, durable, and demonstrate sufficient load-carrying capacity. For this purpose, the load which is designated here as the load-related action must be known with regard to its size, type, and direction. Furthermore, information about the environmental conditions at the location of the fastening which represent actions not related to the load should be known.
With this information and the aid of the product information and a product approval, a suitable fastening system can be selected.

3.1 Load-related actions

Examples of load-related actions are given in Table 3.1. They are categorized primarily according to their frequency of occurrence and their amplitude. If loads act predominantly permanently (e.g. the dead load of the component to be fastened) or if their magnitude changes relatively slowly (e.g. furniture, snow, or persons), they are designated as static actions. If, on the other hand, loads vary quickly, they are called dynamic actions. Examples of dynamic actions are impact loading (e.g. if a car hits a guardrail) or frequently cycled loads (e.g. such as exist for elevators or crane rails). The variation of the load depending on time is shown in Figure 3.1 for different applications. A precise classification of the type of actions may be found in the relevant Eurocodes.

Number of load cycles				
none	few		many	
	without inertial forces	with inertial forces	without inertial forces	with inertial forces
dead load walls people facilities materials in stock snow water wind restraints	restraints	impact loads earthquakes explosions	live loads on bridges crane rails elevators machines without mass acceleration	machines with mass acceleration (e.g. rams, forges)
predominantly static		impact (shock)	pulsating/ alternating	impact
static action		dynamic action		

Table 3.1: Classification of actions

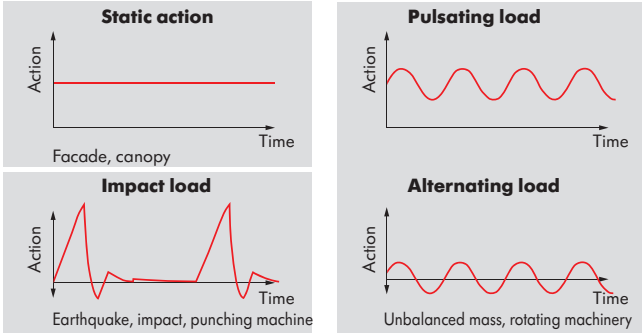


Figure 3.1: Examples of the load time history

The static and dynamic actions can act as tension load, compression load, shear load, and combined tension and shear load under a certain inclination to the axis of the fastener (Figure 3.2). It must be noted that all types of expansion and undercut anchors cannot transfer compression loads into the base material. If the fixture is installed with distance to the base material (stand-off installation), a combined action with shear load and bending or inclined load and bending can act on the fastener (Figure 3.3). In the cases where there is no restraint on the concrete surface (Figure 3.3b) a shell shaped concrete break out can occur at the surface in front of the fastener. In the design this is considered by increasing the lever arm e_1 by the value a_3. If there is restraint (Figure 3.3 c) the lever arm equals the distance from the line of action of the existing load to the concrete surface.

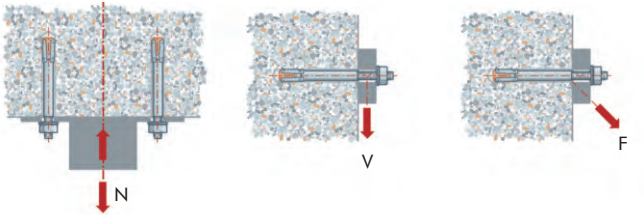
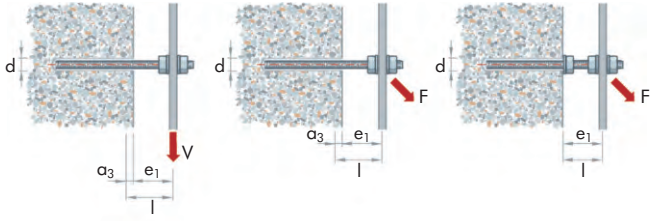


Figure 3.2: Load directions



a) Bending

b) Combined tension and bending

c) Combined tension and bending

Figure 3.3: Actions on a fastener in stand-off installation

3.2 Actions unaffected by the load

The service life of a fastening is expected to be at least as long as that of the structure in which it is installed. This requires fastening system materials which are resistant against environmental impacts.

Actions unaffected by the load (environmental actions) such as polluted air and acid rain can wear away the protective coatings, e.g. zinc on the fastener surface. This leads to corrosion of the fastener which weakens its cross-section, unfavourably affects its functioning, and patches of rust can negatively influence the appearance of the fastening.

Furthermore, temperatures of 80 °C and more can occur at fastenings at European latitudes under direct solar radiation. The plastic of a plastic anchor or the adhesive of a chemical fastener must be able to resist these actions induced by temperature. Further temperature related actions are frost and fire.

During the selection of a fastener for a certain application the environmental actions shall be considered (Figure 3.4) and the influences of air, temperature, and humidity have to be taken into account.

The product information and approvals provide the necessary information.

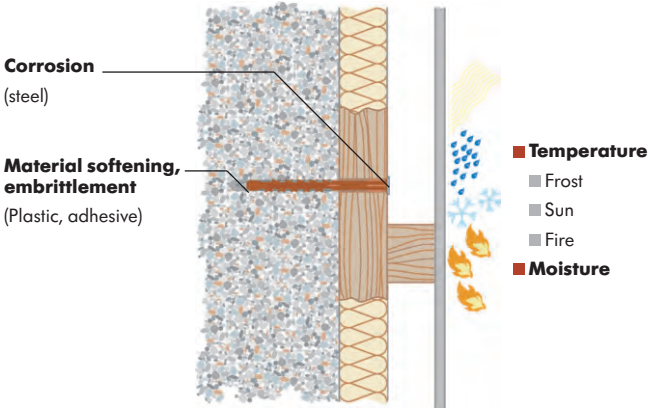


Figure 3.4: Environmental actions

4. Installation and functioning

4.1 General

A fastener can fulfil its intended task and function correctly only if it is properly installed.
For the installation of fasteners, a hole is usually drilled into the base material, then the fastener is inserted into the drilled hole and set according to the manufacturer's installation instructions. For some products special installation tools are required to engage the anchorage mechanism.
The hole should always be drilled perpendicular to the surface of the base material. Damage to or complete cutting of reinforcement bars in a reinforced concrete component during the drilling process must be avoided. The load-carrying capacity of the building component can be significantly reduced by damaged reinforcement. Furthermore, the load-bearing behaviour of the fastener might be influenced unfavourably. Therefore, it is recommended to locate and to mark the position of the reinforcement by means of a rebar detecting device before drilling, so that reinforcement damage and improper drilled holes can be avoided.
When determining the maximum fixture thickness, the height of the non-bearing layer (if one is present), e.g. grout, as well as the height of the element to be fixed should be considered (Figure 4.1).
For the design of the fastener it is assumed that the clearance hole diameters in the fixture are not larger than the values given in Table 4.1 and that the fixture does not deform under the acting loads. Therefore, the fixture should be sufficiently stiff and, except for stand-off installations, lie in direct contact with the base material or a thin non-bearing layer. If the hole diameters in the fixture are larger than the values in Table 4.1, the load-bearing capacity of the fastener will be reduced.

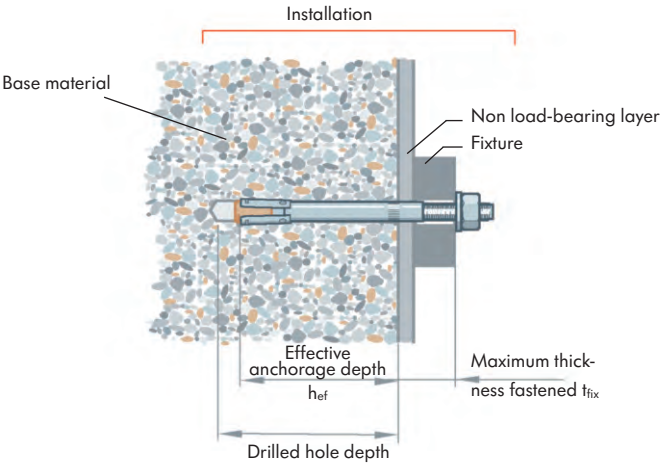


Figure 4.1: Installed fastener

	Diameter of the fastener in contact with the fixture (mm)[1)]											
	6	8	10	12	14	16	18	20	22	24	27	30
Maximum allowable hole diameter d_f in the fixture (mm)	7	9	12	14	16	18	20	22	24	26	30	33

[1)] Nominal diameter of the sleeve or bolt in in-place installations or diameter of the screw or bolt in pre-positioned installations

Table 4.1: Maximum hole diameters in the fixture

During installation of the fastening attention has to be paid to the requirements of the relevant approval. The approval document must be on site during installation. If there is no approval for the fastener or for the specific application, the requirements recommended by the manufacturer which are given in the installation instructions, technical data sheets, and product information should be considered.
Components of fasteners should never be removed or exchanged. This would prevent the fastener from functioning properly. Improperly installed fasteners should never be reused.

4.2 Drilling

The load-bearing behaviour of most fastening systems is influenced by the borehole geometry. The hole geometry is influenced by the type of drill used and the manner in which the hole is drilled. The product approval and manufacturer's installation instructions provide information on the selection of the proper drilling setup.

4.2.1 Drilling methods

The most common techniques for drilling of holes in concrete and masonry are

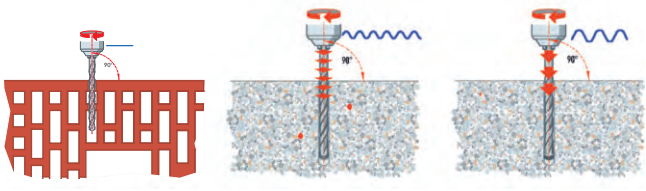
- standard rotary drilling,
- impact drilling,
- rotary-hammer drilling,
- diamond-core drilling.

During standard rotary drilling the borehole is generated without any impact or hammer effect (Figure 4.2a). The hole is created by the rotation of the drill-bit with simultaneous pressure applied by the operator. The borehole is 'cut' out of the base material. Standard

rotary drilling is used in solid materials with low strength, e.g. aerated concrete and perforated masonry units. For these materials only standard rotary drilling (i.e. hammering action of the drill machine turned off) may be used since through application of the impact or hammer-drilling techniques the drilled hole diameter becomes too large for the fasteners and/or the webs in perforated masonry units may be crushed. This damages the base material (see Section 5.7).

Impact drilling (Figure 4.2b) is mainly applied in solid materials with low strength, e.g. solid masonry units or low-strength concrete. The borehole is generated by rotation and impact. Drilling occurs according to the principle 'rotation + pressure + impact'. A ratchet disk is brought in contact with the rotating drive mechanism in the drill. As the operator applies pressure to the drill, the drill-bit is simultaneously rotated and impacted. Impact drilling is characterized by a high impact frequency (40.000 to 50.000/minute) with relatively low energy.

Rotary-hammer drilling (Figure 4.2c) occurs by rotation and hammering of the drill-bit. The difference to impact drilling is that the impact motion is being generated pneumatically. The hammer-strokes (impact) are delivered to the drill-bit by a piston. The hammer-stroke frequency is about 1/10th of that for the impact drilling. The energy introduced into the drill-bit, however, is much higher. Rotary hammers are used for generating holes in concrete. Drilled holes for fasteners must maintain specified tolerances.



a) Standard rotary drilling b) Impact drilling c) Rotary-hammer drilling

Figure 4.2: Drilling methods

Diamond-core drilling is a vibrationless drilling technique (Figure 4.4). A drilling core is cut from the concrete using a rotating motion and a special drill-bit with industrial diamond flakes. Diamond-drilling procedures with and without water rinsing exist. Diamond-core drilling is used mostly to generate holes with larger diameters, boreholes which require smooth walls, and particularly for drilling in high-strength concrete. A complete cutting of reinforcement is possible without problems. In general, creating holes by means of diamond-core drilling techniques is expensive and with few exceptions not allowed for most fastening systems. More detailed information on this topic is provided in the product approvals and product information of the fastening systems.

Figure 4.4: Diamond-core drilling

4.2.2 Aborted holes

Aborted holes are boreholes that

- were drilled at the false location, or
- because of contact with the reinforcement bars do not reach the necessary drilling-depth, or
- contact reinforcement bars such that fasteners can not be installed properly.

Fastening in aborted holes is not allowed. For the case of aborted holes, provisions are given in the product approvals for the spacing between the aborted and new drilled hole (Table 4.2).

Type of fastener	Spacing/required actions [1)]
Expansion anchor	≥ 2x the depth of the drilled hole and mortar-mix of aborted hole
Plastic anchor	≥ 2x the depth of the drilled hole and mortar-mix of aborted hole and > 5x the diameter of the fastener
Adhesive anchor	No requirements with regard to the spacing of the aborted hole; mortar-mix of the aborted hole
Bonded expansion anchor	No requirements with regard to the spacing of the aborted hole; mortar-mix of the aborted hole

[1)] Details are regulated in the approval of the respective product or in the manufacturer's information

Table 4.2: General provisions of the product approvals with regard to aborted holes

The precise provisions can be taken from the relevant product approvals and product information.

4.2.3 Rough assessment of the type of base material

If there is no precise information concerning the base material or if the base material is hidden by a layer (e.g. plaster), a rough determination of the type of the base material can be carried out by means of Table 4.3.

Advance of the drill-bit	Condition	Colour of drilling dust	Base material
Constant and slow	Solid	Grey	Concrete, concrete masonry unit
		Red	Clay masonry unit
		White	Limestone
Constant and fast		White	Aerated concrete
Erratic	Perforated	Grey	Perforated concrete block
		Red	Clay masonry unit with voids
		White	Limestone with voids

Table 4.3: Rough determination of the type of base material

For example, if the advance of the drill-bit in a masonry unit is erratic during standard rotary drilling, voids in the masonry unit are cut. Furthermore, if the drilling dust is grey, a perforated concrete block may be expected.

4.3 Types of installation arrangements

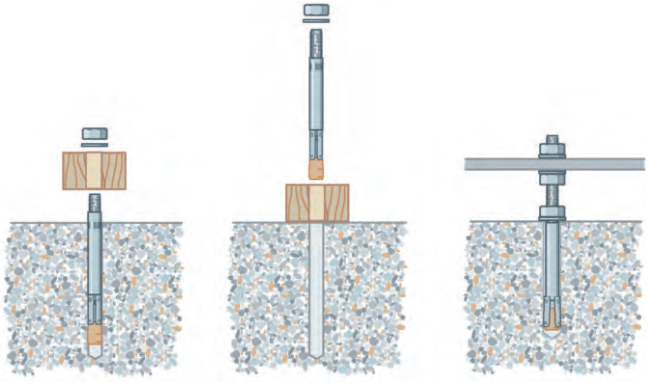
In the post-installed fastening technology it is distinguished between prior insertion installation (Figure 4.5a), push-through insertion installation (Figure 4.5b), and stand-off installation (Figure 4.5c).

In pre-positioned installation (Figure 4.5a) the desired location of the drilled hole is first marked, then drilled, then the fastener is inserted and the fixture is put in place. Finally, the fastener and the fixture are

screwed together. The diameter of the fastener and the borehole are not identical for this type of installation.

For in-place installation (Figure 4.5b) the fixture is first positioned, the hole is then drilled into the base material through the hole of the fixture, the fastener is pushed through the fixture and installed without the fixture having to be removed again. This type of installation is preferred for heavy or complicated equipment as well as for the installation of fastener groups. In-place installation eliminates the need for marking of every fastener hole location and reduces the possibility of aborted holes.

Stand-off installation (Figure 4.5c) is used frequently for cladding. The fixing point is located in a distance from the base material. This is achieved by fasteners using extra long fasteners or threaded bars in the case of fasteners with internal threads. The fastening system will be loaded by an additional bending moment.



a) Pre-positioed b) In-place c) Stand-off installation

Figure 4.5: Types of installation arrangements

4.4 Installation of fastening systems

4.4.1 General

During installation, the relevant fastener approvals and the installation instructions should always be taken into account. If there is no approval available, the manufacturer's recommended installation instruction should be used.
Before and during the installation process the following should be considered:

- Anchor ground
  - Condition of the anchor ground on site (strength, cracked, or non-cracked concrete?)
  - Actual dimensions of the building component serving as the anchor ground (depth, width, length?)
  - Is the fastener selected correctly?

- Fastener
  - Is the approval/installation instruction for the fastener on site?
  - Number and period of validity of the approval
  - Is the maximum thickness to be fastened (e.g. fixture thickness) correct?
  - Does the fastener material (galvanized/stainless steel) fulfil the requirements of the intended use?

- Fixture
  - Do the thickness of the fixture and hole diameters correspond to the approval?

- Installation
  - Which drilling method is required by the approval/installation instruction?
  - Which drilling machine should be used?

- Which drill-bits are required (cutting edge, drill-bit length)?
- Is the building component reinforced? Is there reinforcement in the area of the anchorage?
- Which tools are required for the fastener installation?
- Which type of installation arrangement is required? Is in-place installation possible?
- Is it possible to drill the holes vertical to the surface of the base material with the hole depth according to the approval/installation instructions?
- Procedure of removing dust and debris from the borehole according to the requirements of the approval/installation instructions?
- Insertion installation and installation assembling of the fastener according to the requirements of the approval/installation instructions?
- Installation of the fixture according to the requirements of the approval/installation instructions?
- Use of a calibrated torque wrench for installation?
- Is a check of correct installation required by the approval?
- Writing and filing of the installation protocol according to the requirements of the approval?
- Keep the file with the installation protocols together with the fastening contract for at least five years.

4.4.2 Expansion anchors

Expansion anchors are available in zinc plated carbon steel (layer thickness ≥ 5 µm) or stainless steel and may be used only in concrete. They function after the working principle of 'friction'. The load acting on the fastener is transferred into the base material by friction between the expansion sleeve and the wall of the drilled hole.
Expansion anchors are subdivided into torque-controlled and displacement-controlled expansion anchors.

4.4.2.1 Torque-controlled expansion anchors

Torque-controlled expansion anchors are anchored by applying a defined torque to the nut or screw with a calibrated torque wrench. During torquing a prestressing force is produced in the screw or bolt and the cone is pulled into the expansion sleeve or segments. These are pressed against the wall of the drilled hole (Figure 4.6). The expansion force acts only over the length of the cone.

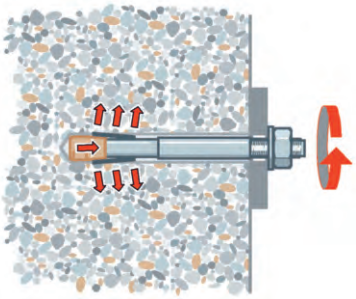
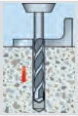
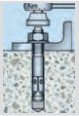


Figure 4.6: Working principle of a torque-controlled expansion anchor (friction between the surface of the expansion segments sleeve and wall of the drilled hole)

Tolerances in the drilled hole can be compensated by torque-controlled expansion anchors to a certain degree by pulling the cone a greater distance into the expansion sleeve or segments. The installation torque is specified by the approval and is used as a check for correct installation. Fasteners can be considered to be properly installed only if during the setting operation the specified torque could be applied and the fastener could be expanded which leads to a prestressing force in the fastener. Therefore, the fastener should always be torqued with a calibrated wrench. Otherwise, the fastener should not be loaded.

The applied installation torque fulfils two important functions for torque-controlled expansion anchors. It serves as a way of checking that the fastener is properly installed and clamps the fixture against the base material.

Torque-controlled expansion anchors transfer external loads into the base material mainly via friction. If the external load exceeds the pre-stressing force, the expansion cone is pulled further into the expansion sleeve. This process which is designated as 'follow-up expansion' maintains the bearing capacity of the fastener.
Examples of torque-controlled expansion anchors are the Würth W-FAZ Fixanchor (bolt type – Figure 4.7) and the Würth W-HAZ High-Performance anchor (sleeve type – Figure 4.8). The installation of these fasteners is shown in the accompanying pictograms.

				
Figure 4.7: In-place installation with the Würth W-FAZ/S bolt type anchor *Figure 4.8: In-place installation with the Würth W-HAZ sleeve type anchor*	Drill hole using a rotary-hammer and the pre-scribed drill-bit	Clean the drilled hole	Using a hammer, gently hammer the fastener through the fixture and into the drilled hole	Tighten bolt to the specified torque using a calibrated torque wrench

4.4.2.2 Displacement-controlled expansion anchors

Displacement-controlled expansion anchors, also known as drop-in anchors, are fasteners with an internally threaded steel shell and a tapered expansion plug. They are produced in galvanized carbon steel and stainless steel. In-place installations are not possible with these types of fasteners. They are installed by hammering the expansion plug a defined distance into the sleeve with a special setting tool. Displacement-controlled expansion anchors introduce external loads into the base material mainly via friction (Figure 4.9). The expansion is restricted to the height of the cone. Displacement-controlled expansion anchors do not undergo 'follow-up expansion'.

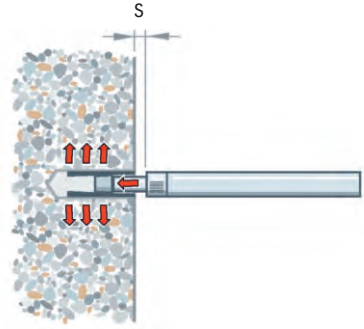


Figure 4.9: Working principle of a displacement-controlled expansion anchor (friction between the surface of the sleeve and the wall of the drilled hole)

The expansion force of displacement-controlled expansion anchors created by hammering the expansion plug into the sleeve is considerably larger than with torque-controlled expansion anchors. Consequently, the values for minimum edge distance and fastener spacing are also larger.

Displacement-controlled expansion anchors are sensitive to tolerances in the diameter of the drilled hole and to incomplete expansion of the sleeve. Therefore, it is especially important to use certified drill-bits where the specified tolerances are maintained. Furthermore, the depth of the hole should be exactly as given in the product approval

or the manufacturer's recommendations. The top of the sleeve should be flush with the concrete surface and the chosen length of the bolt to attach the fixture must be correct. The anchor is properly expanded if the setting tool is driven into the fastener sleeve by hammer blows and its shoulder contacts the top of the sleeve. Proper installation is only possible with the aid of the special setting tool. For proper installation especially in high-strength concrete or for borehole diameters at the bottom of the tolerance limit a large number of hammer blows is necessary. Therefore, checks to ensure correct installation must be carried out. This check is simplified if the setting tool leaves an indentation on top of the sleeve after installation. The fixture is correctly attached when the bolt is torqued with the prescribed torque and

<table>
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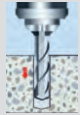
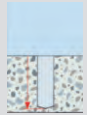
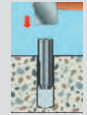
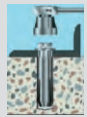
Figure 4.10: Pre-positioned installation of the Würth W-ED/S and W-ED/A4 anchors</td><td>  </td><td>  </td><td> </td><td>  </td></tr>
<tr><td>Drill hole using a rotary-hammer and the prescribed drill-bit</td><td>Set embedment depth such that the top of the fastener sleeve is flush with the concrete surface when installed</td><td>Clean the drilled hole</td><td>Hammer the fastener into the hole with light hammer blows</td></tr>
<tr><td> </td><td>  </td><td></td><td></td></tr>
<tr><td>Expand the fastener using the proper setting tool</td><td colspan="3">Attach the fixture, check the length of the bolt, tighten the bolt to the specified torque using a calibrated torque wrench</td></tr>
</table>

clamped firmly against the base material. A calibrated torque wrench should be used for installation. Limiting the torque prevents the sleeve of the fastener or the bolt from failing during installation.
Figure 4.10 shows a Würth W-ED/S and W-ED A4 fastener with the corresponding setting tool and a description of the installation process.

4.4.3 Screw Anchor

The screw anchor cuts a thread into the wall of the drilled hole when it is screwed into the concrete (Figure 4.13). Tension forces are then transferred into the base material by diagonal struts, i.e. mechanical interlock (Figure 4.14).

Figure 4.13: Concrete screw and a thread cut into concrete [2]

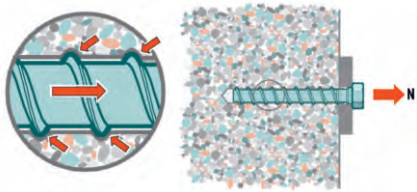


Figure 4.14: Load transfer of concrete screws (mechanical interlock)

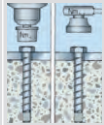
The load-bearing behaviour can be compared to that of reinforced bars cast into concrete. The thread flanks of a screw anchor have a function comparable to that of ribs of a deformed reinforcing bar which is load transfer. However, there are also significant differences between screw anchors and deformed reinforcing bar. Damage respectively failures in the area of the thread cut in the concrete can reduce the mechanical interlock. These failures reduce the undercut area of the thread. In order to enable installation of a screw anchor the core diameter has to be smaller than the drill hole diameter.
Figure 4.15 shows the installation process for a Würth W-SA screw anchor.

Figure 4.15: Installation of a Würth W-SA screw anchor.

Drill hole using a rotary-hammer and the prescribed drill-bit

Clean the drilled hole

Position the fastener



Screw the anchor into the hole to the specified torque using a calibrated torque wrench

4.4.4 Fasteners for suspended ceilings

Fasteners for suspended ceilings are used for the fixing of lightweight non-structural elements with a maximum load of 1 kN/m² in concrete. In principle they are small torque-controlled or displacement-controlled expansion anchors of the sizes M6 and M8 with embedment depths up to approximately 40 mm. Their installation corresponds to that of the above-mentioned fastener types.

Due to their small dimensions, fasteners for suspended ceilings have a relatively small expansion capacity. To assure consistent fastener performance it is especially important that certified drill-bits are used for drilling the holes.

Screw anchors are frequently used as fasteners for suspended ceilings. The above-mentioned points apply.

4.4.5 Plastic anchors

Plastic anchors used for safety-relevant applications should only be purchased as a complete system with a plastic sleeve and a corresponding special expansion element (screw or nail). The length, diameter, and thread of the supplied expansion element are designed such that in combination with the corresponding plastic sleeve an optimal load-bearing behaviour is obtained. A collar on the sleeve helps to prevent it from slipping into the borehole. Moreover, the required embedment depth is marked on the plastic sleeve. Improper installations can be avoided if these measures are followed.

During installation the temperature of the base material has to be considered. In the European technical approvals for plastic anchors the minimum installation temperature depends on the product and is stated in the respective approval.

Plastic anchors can be categorized according to whether they are intended for applications in concrete or solid, perforated or hollow masonry units. Therefore, plastic anchors are classified in the following use categories in European technical approvals:

Use category	Base material
a	Concrete
b	Solid masonry
c	Hollow or perforated masonry
d	Autoclaved aerated concrete

Table 4.4: Combinations of the various use categories are possible

They consist of a plastic sleeve with an expansion mechanism and a special expansion element (Figure 4.16, Figure 4.17). Moreover, there are nailed-in anchors (Figure 4.18). The expansion sleeve is slotted and has features to avoid twisting of the plastic sleeve during installation and dismantling.

The plastic sleeve is expanded by screwing the special screw (Figures 4.16 and 4.17) or hammering the nail (Figure 4.18) into the sleeve. The special screw or nail is to be inserted so that its head is flush with the collar of the plastic sleeve. This causes the tip of the screw or the nail to penetrate the end of the plastic sleeve. The special expansion element cuts into the plastic sleeve and simultaneously presses the sleeve against the wall of the drilled hole.

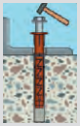
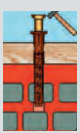
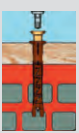
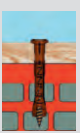
					
Figure 4.16: Installation of the Würth plastic anchor W-UR for applications in concrete	Drill hole using a rotary-hammer and the prescribed drill-bit	Clean the drilled hole	Install the fastener and the screw	Screw the special expansion element (screw) into the hole	Tighten the screw until its head is flush with the collar on the sleeve
					
Figure 4.17: Installation of the Würth plastic anchor W-UR for applications in masonry	Drill hole using a rotary-hammer and the prescribed drill-bit	Clean the drilled hole	Install the fastener and the screw	Screw the special expansion element (screw) into the hole	Tighten the screw until its head is flush with the collar on the sleeve

Figure 4.18: Installation of the Würth nail-in anchor for applications in concrete and masonry

Drill hole using a rotary-hammer

Clean the drilled hole

Push the fastener into the hole

Hammer the special expansion element (nail) into the sleeve until the head is flush with the collar on the sleeve

In solid base material (normal strength concrete and solid masonry units) the fasteners function due to friction between the sleeve and the wall of the drilled hole. The plastic sleeve is too soft to deform the base material. In perforated and hollow masonry units plastic anchors also transfer loads mainly by friction. An additional small contribution to the load-bearing, however, is supplied by the mechanical interlock of the sleeve with the webs of the masonry units. To ensure that the sleeve is pressed against the webs, the position of the expansion area of the sleeve is matched to the different void patterns of the masonry units. In hollow masonry units the holes should normally be drilled by standard rotary drilling, i.e. no hammering motion. Otherwise, the webs can be significantly damaged during drilling, which effects the load-bearing behaviour unfavourably, the capacity of the fastener will be considerably reduced.

4.4.6 Bonded anchors

For fastening with bonded anchors, a threaded rod or internally threaded shell is typically fixed in a predrilled hole in a base material using a two part chemical compound (mortar). A distinction is made between applications in concrete and masonry.

External tension loads are transferred into the base material via bonding. This can either happen by bonding between the bonded mortar and the steel rod as well as by bonding between the mortar and the wall of the drilled hole (Figure 4.19). Bonded anchors may be subdivided into capsule type or injection type fasteners according to the type of installation.

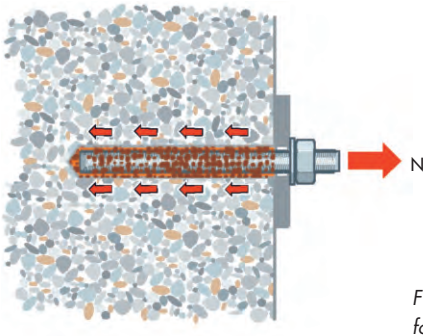


Figure 4.19: Load transfer for bonded anchors

The curing of the mortar depends on the type of mortar, the composition, and the temperature in the base material. A waiting period exists between the installation and loading of the anchors. For base material temperatures of 10 °C to 20 °C the waiting period is approximately 20 to 45 minutes depending on the type of mortar. At the minimum use temperature of e.g. -5 °C the waiting period is several hours. Precise specifications for the waiting period are contained in the

product approvals and product information. For injection type bonded anchors this information is also printed on the mortar cartridge.

A good bond between concrete and mortar is only achieved if the bonded anchor is properly installed according to the installation instructions. Special attention must be paid to a careful cleaning of the drilled hole.
During the installation of bonded anchors no expansion forces are developed. They arise, however, during torquing and loading of the fastener. These expansion forces, however, are considerably smaller than for expansion anchors. This enables small fastener spacing and edge distances and minimum member thicknesses during installation.
For anchorage to masonry injection type bonded anchors are frequently used. In solid masonry units the load transfer occurs as in concrete via bonding of the materials (Figure 4.19). In perforated and hollow masonry units the injection mortar pressed into the cavities of the units forms a mechanical interlock with the webs (Figure 4.20). Therefore, injection type bonded anchors mainly transfer the loads into masonry by mechanical interlock.

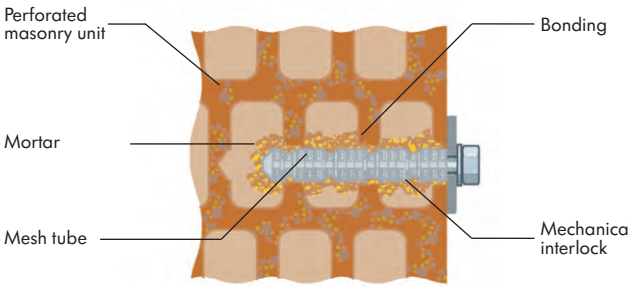
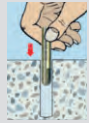
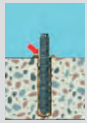
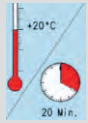


Figure 4.20: Anchorage of injection type bonded anchor in perforated masonry units by a combination of bonding and mechanical interlock

4.4.7.1 Capsule systems

Capsule systems for use in non-cracked concrete consist of a cylindrical glass capsule containing resin, accelerator, mineral aggregates, and a threaded rod or internally threaded shell with a chiselled end and a marking for the embedment depth. The threaded rod or inter-

<table>
<tr><td rowspan="2">
Figure 4.21: Pre-positioned installation of a Würth W-VD in non-cracked concrete</td><td>
Drill hole using a rotary-hammer and the prescribed drill-bit</td><td>
Clean the drilled hole</td><td>
Resin should have the consistency of honey</td><td> 
Insert the glass capsule</td></tr>
<tr><td>
Using a special adapter, hammer drill the insert through the capsule until the embedment depth mark is level with the concrete surface</td><td> 
Check for excess mortar and the proper embedment depth</td><td> 
Check curing time (depends on temperature of the base material)</td><td>
Attach the fixture applying the specified torque using a calibrated torque wrench</td></tr>
</table>

nally threaded shell is usually made of galvanized carbon steel or stainless steel. A single glass cartridge should be used for every anchorage. Installation of a capsule system is shown in Figure 4.21.
A glass capsule is first inserted in a cleaned drilled hole. Setting of the anchor is accomplished by hammer drilling through the capsule with a threaded rod or sleeve chucked in a rotary-hammer by means of an adapter. The glass capsule is destroyed and the rotating and hammering action mixes the contents of the capsule with the fractured fragments of the capsule. The drill rotation should be stopped immediately upon reaching the bottom of the hole. The fractured glass and aggregate components serve to improve bond by scouring the wall of the drilled hole during installation. The amount of mortar is such that after reaching the required embedment depth, excess mortar appears at the concrete surface. This indicates proper bonding of the threaded expansion element and is used as a check for proper installation.

4.4.7.2 Bonded expansion anchors

In order to transfer tension loads into cracked concrete bonded expansion anchors were developed.
The bonded expansion anchor shown in Figure 4.22 has an anchor rod with several cones. It is installed like a common capsule type or injection type bonded anchor in a predrilled cylindrical hole.

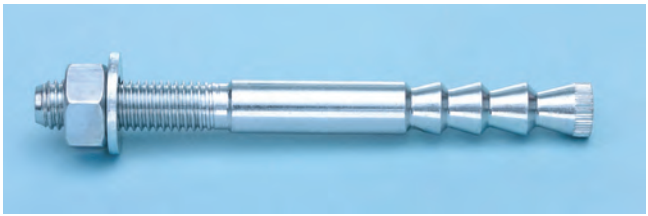


Figure 4.22: Bonded expansion anchor W-VIZ

If the fastener is loaded by tension forces the cones are pulled into the mortar which operates as an expansion sleeve. The tension load produces spreading forces and thereby frictional holding capacity in the concrete base material. This type of bonded anchors functions similarly to torque-controlled expansion anchors. Fastener spacing and edge distance, however, are smaller.
Installation of the anchor shown in Figure 4.22 is carried out according to Figure 4.23 and can be compared to that of injection type anchors.

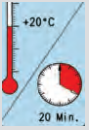
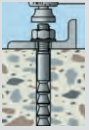
a) Drill hole using a rotary-hammer and the prescribed drill-bit	b) Clean the drilled hole (blowing and mechanical brushing)	c) Check the temperature	d) Screw static mixer onto the cartridge	e) To ensure correct composition, dispense first 100 mm of mortar
				
f) Inject mortar starting at the bottom of the hole	g) Insert the anchor rod using a rotating motion until embedment depth is reached	h) Check for excess mortar and proper embedment depth	i) Check curing time (depends on temperature of the base material)	j) Attach the fixture applying the specified torque using a calibrated torque wrench

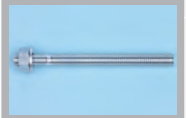
Figure 4.23: Installation of Würth W-VIZ bonded expansion anchor

4.4.7.3 Injection type bonded anchor

Injection type bonded anchors are used in solid and perforated masonry units.

In general, injection type bonded anchors consist of two components. The cartridge contains preconfigured amounts of resin and accelerator. Figure 4.24 shows the components and the installation process of an injection type bonded anchor without screen tube. Resin and accelerator are dispensed with a special dispenser suitable for the cartridge and through a special static mixer when they are injected into the drilled hole. The threaded rod or the internally threaded shell are then inserted in the drilled hole using a rotating motion in order to improve the contact between the fastener and the mortar. Air bubbles in the mortar should be avoided during installation. Therefore, it is important to start injecting the mortar into the drilled hole at the bottom of the hole and that the tip of the static mixer does not leave the mortar during injection. Otherwise, the load-bearing capacity is likely to be significantly reduced.

The injection type bonded anchor shown in Figure 4.25 consists of a plastic mesh tube, an anchor rod with nut and centring ring respectively an internally threaded shell, and mortar on an organic base, preconfigured in cartridges. It is approved for applications in perforated masonry units. The mesh tube is pushed into the drilled hole such that its top is flush with the stone surface and then completely filled up with mortar. The threaded rod or the internally threaded shell are pushed into the mesh tube filled with mortar: The anchor rod until it reaches the ground of the mesh tube, the internally threaded shell such that its top is flush with the surface. The mortar is pressed through the mesh of the mesh tube, finds its way into the drilled voids of the stones and, therefore, leads to mechanical interlock with the base material. Before the fixture is installed the prescribed hardening time should be regarded.



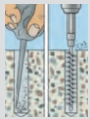
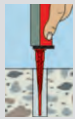
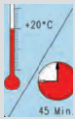
Drill hole using a rotary-hammer and the prescribed drill-bit	Check the diameter of the cleaning brush	 Clean the drilled hole (4x blowing, 4x brushing by machine, 4x blowing)	Check the temperature
Screw static mixer onto the cartridge	To ensure correct composition, dispense first 100 mm of mortar	 Inject mortar starting at the bottom of the hole	Insert anchor rod using a rotating motion until the embedment depth is reached
Check for excess mortar and proper embedment depth	 Check curing time	Attach the fixture applying the specified torque using a calibrated torque wrench	

Figure 4.24: Pre-positioned installation of a Würth W-VI/S in non-cracked concrete

Drill hole using a rotary-hammer and the prescribed drill-bit	Check the diameter of the cleaning brush	Clean the drilled hole (2x blowing, 2x mechanical brushing, 2x blowing)	Push the mesh tube into the hole
To ensure correct composition, dispense first 100 mm of mortar	Check the temperature	Inject mortar starting at the bottom of the hole (see instruction leaflet)	Insert fastener using a rotating motion until the embedment depth is reached
Check curing time	Attach the fixture applying the specified torque using a calibrated torque wrench		

Figure 4.25: Pre-positioned installation of a Würth WIT-VM 200 in masonry

4.4.8 Special anchors

The majority of fasteners used in construction practice are used for applications that are not safety-relevant. For these types of application Würth offers a wide variety of plastic anchors optimized for the intended application. Some examples are: Nail anchors, special fasteners for plumbing, electrical, heating, and sanitary installations, fasteners for window installation, fasteners for attaching insulating systems.
The large variety of the available special anchors makes a description impossible. Detailed information may be obtained from the Würth experts.

4.5 Fundamental rules for installation

Before the installer obtains and uses a fastening product, he must learn about the product by means of manufacturer's specifications and product approvals. While reading the product approval the following points should be kept in mind:

- Front cover of the approval
  - Registration number
  - Holder of approval (manufacturer)
  - Generic type and use of construction product (fastener, product name)
  - Expiration date of the approval (products with expired approval should not be used)
- Specific conditions
  - Definition of product and intended use
  - Description of the fastener and its components
  - → check whether the supplied fastener agrees with the description
  - Description of the field of application: Cracked and non-cracked concrete, non-cracked concrete only, masonry, etc.

- → check whether the selected fastener applies to the field of application
- Environmental conditions: Dry interior conditions (galvanized steel), wet conditions (e.g. stainless steel A4) or exterior conditions (e.g. stainless steel A4 or HCR)
- → check whether the fastener material is suitable for the application

- Characteristics of product and methods of verification
  - The features and the composition of the fastener have to correspond with the drawings and data in the approval
  - → check the correlation
- Package, storage, and marking
  - The fastener should be packaged and supplied only as a unit
  - → check whether the 'CE' mark is present and that the fastener shows the necessary marking (e.g. W-FAZ, M12, A4)
- Provisions for the design
  - The fastener should be designed with the design method indicated in the corresponding approval
- Provisions for the execution
  - The fastener should only be used as a unit. Single components should not be replaced. The type and strength of base material should be checked before installation
  - → check whether the base material agrees with the field of application given in the approval (e.g. drawing by the designer)
- Drilling
  - Only the drilling method (e.g. rotary-hammer drilling) with the specified drilling tool (e.g. stop drill-bit) indicated in the product approval or installation instructions may be used
  - → check whether the drill-bit is properly marked
  - Reinforcement should not be damaged or cut
  - The drilled hole should be cleaned
  - In the case of aborted holes the provisions of the approvals apply

- Installation of the fastener
  - The hole should be drilled perpendicular to the base material surface
  - The hole depth should agree with the provisions of the approval or installation instruction
  - The fastener should be installed with the specific installation tools (torque wrench, special setting tool)
  - The proper anchorage is to be checked according to the specifications of the product approval or installation instructions (e.g. test load)
- Check of the installation
  - The installation should be carried out by qualified personnel (e.g. a 'Certified Fastening Technician')
  - A written record of the installation work should be made
  - The record should be kept at least five years after completion of the job

5.1 General

The phrase 'load-bearing behaviour' is used to describe both the transfer of load from a fastener to the base material as well as the resistance of a fastener to applied loads (tension, shear, combined tension and shear loads). Bending may be neglected when the following conditions are met for the fastening:

- The fixture which the fastener attaches must be made of metal and be tensioned directly against the surface of the base material without an intermediate layer.
- The fixture must be in contact with the fastener over the entire thickness of the fixture.
- The diameter of the clearance hole in the fixture must not be larger than the allowable diameter d_f according to [3] and [4] (see Table 4.1).

5.2 Undercut anchors and metal expansion anchors

5.2.1 Tension loading in non-cracked concrete

Fastening systems transfer applied loads to the base material by the anchorage mechanisms described in Chapter 4.
Since these mechanisms load the concrete in tension, in many cases failure occurs when the local tension strength of the concrete is exceeded. Under tension load a concrete failure cone with a slope of approximately 35° is formed (Figure 5.1).

Figure 5.1: Concrete failure cone for an anchor loaded in tension

Additionally, the failure modes sketched in Figure 5.2 may occur.

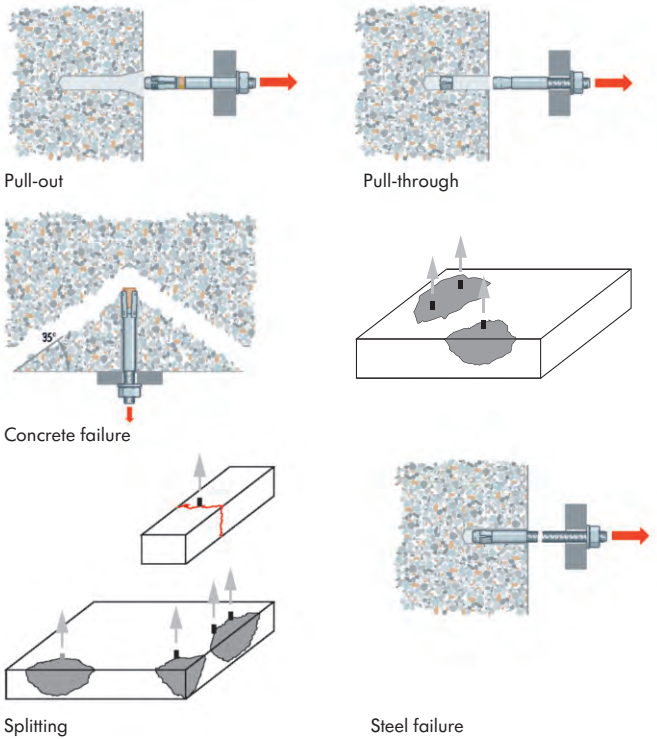


Figure 5.2: Failure modes under tension loading

■ Pull-out

This failure mode occurs when the resistance arising from friction between the expansion elements of the fastener and the wall of the drilled hole is smaller than the applied tension load. The fastener is literally pulled out of the drilled hole. It is possible that the concrete surface near the top of the hole will be damaged during this process.
With displacement-controlled expansion anchors this failure mode occurs when the expansion cone is not properly driven into the expansion sleeve. Incomplete driving of the expansion cone prevents the development of expansion forces sufficient to prevent the anchor from slipping before the concrete failure load is reached.
With torque-controlled expansion anchors this failure mode can also occur if the required follow-up expansion is not achieved. After the resistance due to static friction has been exceeded, load can still be transferred by dynamic friction, which is mainly dependent on the roughness of the wall of the drilled hole. However, since the resistance achieved from the dynamic friction is very sensitive to several parameters (e.g. drilling method, drilled hole roughness) and is thus not reproducible, pull-out is not allowed in approval tests for torque-controlled expansion anchors.
Headed bolts and undercut anchors can also fail by pull-out if the mechanical interlock is insufficient.

■ Pull-through

Properly functioning torque-controlled expansion anchors can fail by pulling the expansion cone through the expansion sleeve, whereby the sleeve remains in the drilled hole. This failure mode is called pull-through.
Pull-through is an allowable failure mode in approval tests for torque-controlled expansion anchors, although pull-out is not allowed.

■ Concrete failure

Concrete cone failure occurs under centric tension loading of a fastener if the local tensile strength of the concrete is exceeded. This is the case for expansion anchors when the resistance developed by friction between the expansion elements of the fastener and the wall of the drilled hole is larger than the local tension strength of the concrete. In other words, the expansion force must be large enough to hold the fastener in place until concrete cone failure occurs.

This failure mode is observed for undercut anchors and headed bolts if the undercut surface is sufficiently large.

Properly installed displacement-controlled expansion anchors frequently fail by concrete cone failure in cracked concrete due to their typically shallow embedment depths and relatively high expansion forces.

■ Splitting

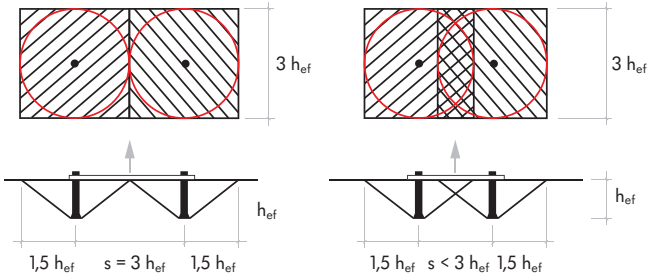
Splitting of the concrete typically only occurs under tension loading when the minimum building component dimensions, edge distances, or fastener spacing required in the product approval are not maintained, i.e. if the dimensions, edge distances, or spacing are too small.

■ Steel failure

Steel failure includes failure of the bolt shaft, the threaded portion of the bolt, or the fastener sleeve. It represents the upper limit of the capacity of a fastener. Steel failure typically occurs for large embedment depths and for anchorage in high-strength concrete. For normal embedment depths, concrete cone failure or pull-through typically occurs.

Figure 5.3: Concrete failure cone for single use

According to experimental results the concrete failure cone forms an angle of approximately 35° with the surface of the concrete. Consequently, the diameter of the failure cone is approximately three times the embedment depth. This results in a critical fastener spacing of $s = 3\ h_{ef}$, beyond which the failure cones of neighbouring fasteners do not intersect and the fasteners do not influence each other. If the fastener spacing is smaller than this value, the concrete cones of neighbouring fasteners can intersect and the failure load of the group is smaller than the maximum possible value determined as the sum of the individual failure cones. When designing for concrete cone failure using the CC Method, the size of the concrete failure cone is determined taking the fastener spacing into account (Figure 5.4). This is done by dividing the actual projected failure cone area of a group A by the projected failure cone area of a single fastener A^0. The ratio A/A^0 multiplied by the concrete cone failure load of a single fastener located far from building component edges and other fasteners yields the failure load of the group. Figure 5.5 shows the increase of the concrete cone failure load of a symmetric 4-fastener group with increasing fastener spacing. For spacing $s \geq 3\ h_{ef}$ no further increase in the failure load occurs. In this case, four individual failure cones would be formed.



a) large fastener spacing b) small fastener spacing

Figure 5.4: Influence of the fastener spacing on the shape of the failure cone (after [7])

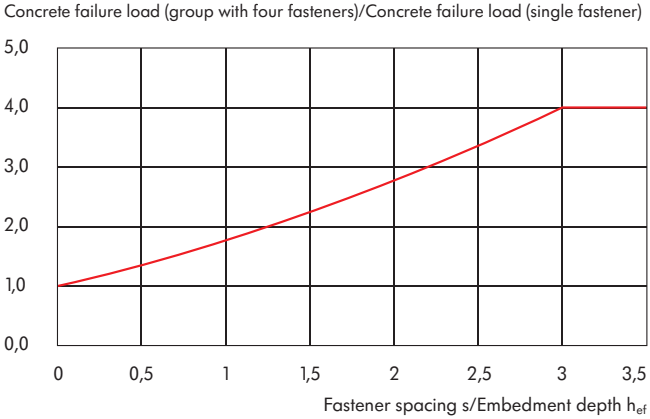


Figure 5.5: Concrete cone failure load for a group with four fasteners relative to the failure load of a single fastener plotted as a function of the fastener spacing

When a fastening element is located near an edge of a building component at a distance less than the critical edge distance c = 1,5 h_{ef}, the failure load of the fastening is reduced. The size of the concrete failure cone is decreased compared to that of a fastener located far from any edges (Figure 5.6). Furthermore, an axisymmetric (circular) stress state is not possible due to the presence of the edge.
The greater the number of edges present and the closer the fastener is located to the edges, the more the failure load decreases compared to that of an 'unaffected' fastener. The extent of the load decrease is shown as a function of the edge distance in Figure 5.7a) (edge) and Figure 5.7b) (corner).

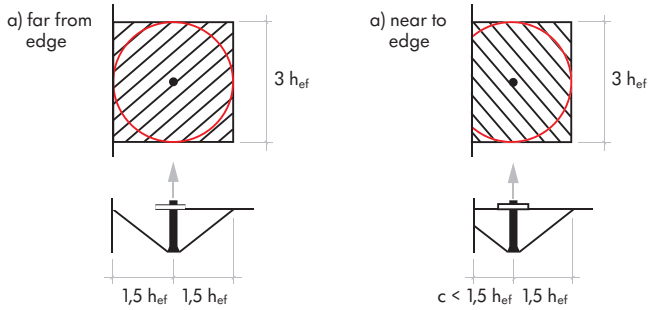
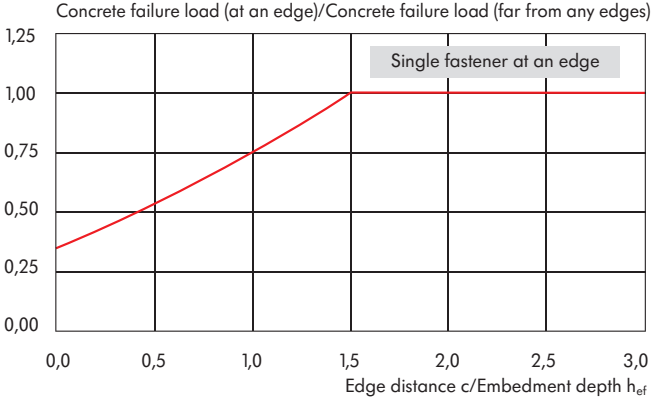
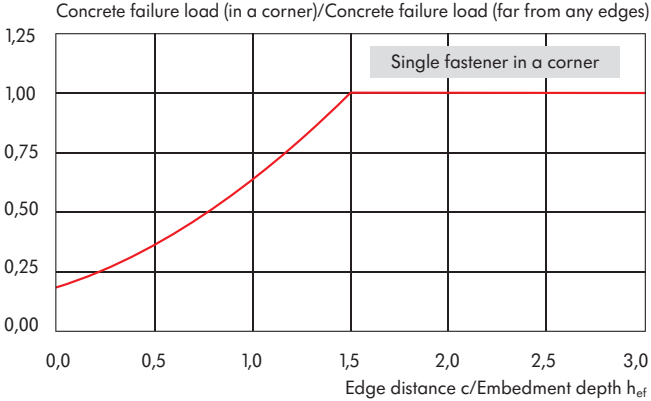


Figure 5.6: Influence of the edge distance on the shape of the failure body (after [7])



a) Influence of the edge distance (building component edge)

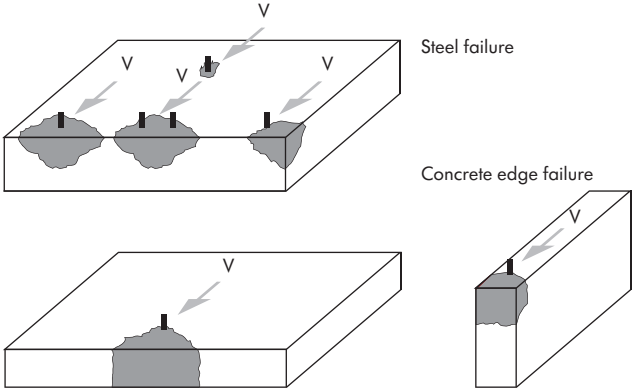


b) Influence of the edge distance (building component corner)

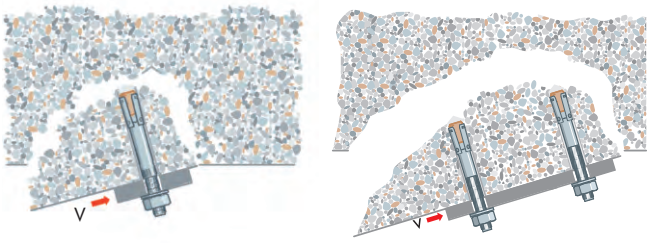
Figure 5.7: Concrete failure load of a single fastener located a) at the edge of a building component and b) in the corner of a building component plotted as a function of the edge distance

5.2.2 Shear loading in non-cracked concrete

The failure modes possible for shear loading of a fastener are shown in Figure 5.8.



Concrete edge failure in thin and narrow building components



Pryout failure (concrete failure on the side facing away from the load)

Figure 5.8: Failure modes for shear loading

■ Steel failure
Steel failure often occurs under shear loading for fasteners located far away from any edges. A wedge shaped spalling of the concrete near to the surface typically occurs just before the ultimate load is reached. The depth of the spalled concrete wedge directly in front of the fastener is about equal to the fastener diameter.

■ Concrete edge failure
Concrete edge failure can occur when a fastening is located close to a building component edge or in a corner and is loaded in the direction of the edge.

■ Concrete pryout
This failure mode occurs for fastenings with shallow embedment depths that are located far away from any edges and are loaded in shear. A composite failure body is formed for fastener groups.

The diameter of the clearance hole in the fixture to which the fastener is attached must not be larger than the allowable diameter d_f according to Table 4.1.
An equal distribution of a shear load to all the fasteners in a group, as shown in Figure 5.9, seldom occurs in practice. The distribution of the shear load depends on

- the size of the clearance holes in the fixture,
- the positions of the fasteners in the holes (with or without contact to the fixture),
- the deformation behaviour of the fasteners.

The true load distribution is extremely difficult to determine analytically. Therefore, in [4] for fastenings located close to an edge it is assumed that the entire shear load for a group with two fasteners, where loading is along the axis formed by the fasteners, is carried by

only one of the fasteners . For 4-fastener groups under the same conditions it is assumed that the entire shear load is taken by only two of the four fasteners (Figure 5.10).

For 2-fastener groups loaded in shear perpendicular to the axis formed by the two fasteners and the fixture is free to rotate, both fasteners act to resist the shear load. If the fixture is not free to rotate, the fastener in direct contact with the fixture carries the entire shear load. In this case it must be shown that the fixture is capable of resisting the induced moment.

According to [3] when the diameters of the clearance holes are larger than the allowable values it may be assumed for steel failure that all of the fasteners act to resist the applied shear load (Figure 5.11). One must account, however, for the fact that all of the fasteners will be subjected to an additional bending moment due to the applied shear load. This leads to a significant reduction in the allowable resistance. Shear load transfer to the fasteners can be controlled by the size and the position of the clearance holes in the fixture (Figure 5.12).

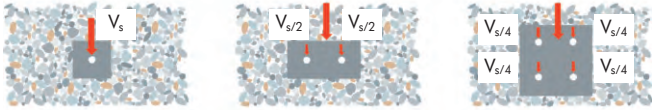


Figure 5.9: Examples of the distribution of load when all of the fasteners participate to carry the shear load

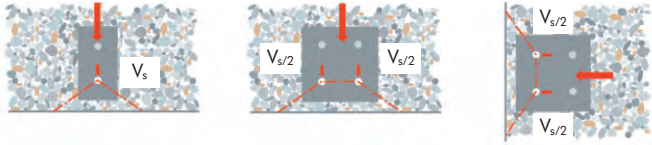


Figure 5.10: Examples of the distribution of load for fastenings located near to an edge

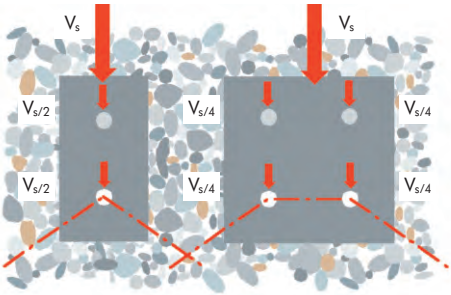


Figure 5.11: Examples of the distribution of load if the hole diameter is larger than stated in [3] and [4] (design with bending moment)

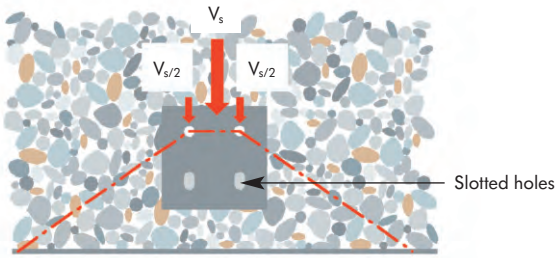
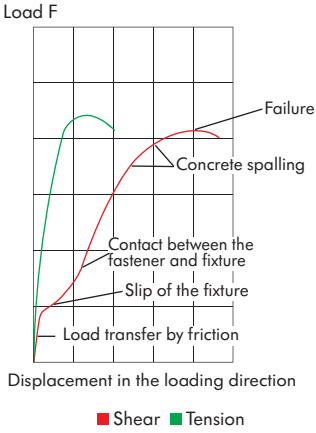


Figure 5.12: Example of the distribution of load for a fixture with slotted holes for the fasteners near to the edge

Increasing the diameter of the clearance holes in the fixture has a significant effect on the load-bearing capacity of the fastening and is thus only approved after consultation with the design engineer.
Figure 5.13 shows a typical load-displacement curve for a fastening located far away from any edges, pretensioned against the base material and loaded to failure in shear. The shear load is transferred to the drilled hole in the concrete on the side of the hole in the direction of loading after the friction between the fixture and the concrete has been exceeded and the gap between the fastener and the fixture clearance hole has been closed. The pressure at the lip of the drilled hole increases with increasing shear load. This leads to the formation



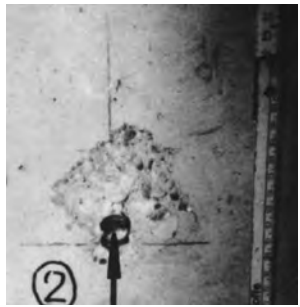


Figure 5.13
a) Typical load-displacement curves for fasteners under tension and shear loading [6]
b) Photograph of a fastener that was located far from any edges and loaded to failure in shear [8]

of a wedge-shaped spalling of the concrete in front of the fastener. If the load is further increased and the edge distance is sufficient, the fastener will eventually be sheared-off. The load-displacement behaviour of a fastener loaded in tension is shown for comparison.

Fastenings located near to an edge can fail by concrete edge failure before the steel failure load is reached.

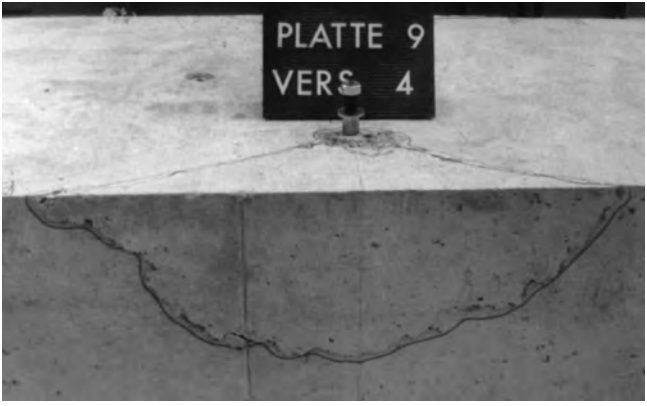


Figure 5.14: Concrete failure of a fastener located near to an edge and loaded in shear towards the edge [9]

5.2.3 Combined tension and shear loading in non-cracked concrete

The load-bearing behaviour of fastenings under combined tension and shear loading lies somewhere between that for centric tension and pure shear loading. The behaviour is influenced by the angle of the applied load. The same failure modes as for pure tension and shear loading are observed. The following combinations of failure modes a) to d) can occur:

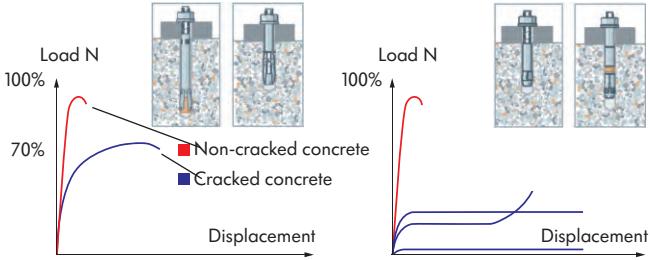
	Tension	Shear
a)	Steel failure	Steel failure
b)	Concrete failure	Steel failure
c)	Concrete failure	Concrete failure
d)	Steel failure	Concrete failure

5.2.4 Tension loading in cracked concrete

In general, undercut anchors function well in cracks, whereby metal expansion anchors and bonded anchors must be specially designed for this purpose.

A reduction of the concrete cone failure load of approximately 30 % can be expected for an undercut anchor located in a crack compared to the value in non-cracked concrete. Furthermore, somewhat larger displacements will be present with increasing load.

The load-displacement behaviour of torque-controlled expansion anchors is governed by the follow-up expansion capability of the fastener. Expansion anchors that are suitable for use in cracked concrete exhibit a similar load-displacement behaviour to that of undercut anchors (Figure 5.15a). These fasteners function in cracks because the expansion cone is pulled further into the expansion sleeve as the crack width increases (follow-up expansion). Expansion anchors that are not suitable for use in cracked concrete exhibit a much lower failure load relative to that in non-cracked concrete when they are located in a crack. For these fasteners follow-up expansion does not typically occur and the fastener experiences significant displacement at very low loads (Figure 5.15b). The behaviour of displacement-controlled expansion



a) Fasteners suitable for use in cracked and non-cracked concrete

b) Fasteners suitable for use in non-cracked concrete and fasteners not suitable for use in cracked concrete (problematic follow-up expansion)

Figure 5.15: Schematic load-displacement curves for torque-controlled expansion anchors in non-cracked and cracked concrete under centric tension load [8]

anchors located in cracked concrete is in general the same as for torque-controlled expansion anchors that are not suitable for use in cracked concrete. If a drop-in anchor is properly expanded during installation, a flat load-displacement curve with a significantly reduced ultimate load compared to that in non-cracked concrete can be expected. If the fastener is not properly expanded during installation this tendency is magnified.

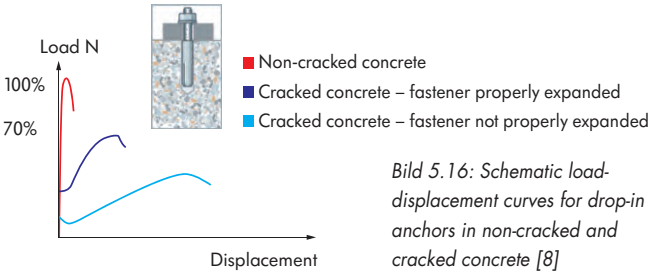


Bild 5.16: Schematic load-displacement curves for drop-in anchors in non-cracked and cracked concrete [8]

The load-bearing capacity of all fastening systems is reduced in cracked concrete compared to that in non-cracked concrete. The reduction of the ultimate load in crack widths of approximately 0,3 mm is usually at least 30 % for systems suitable for use in cracked concrete and can be 90 % or more for systems that are not suitable for use in cracked concrete. For torque-controlled expansion anchors the extent of the reduction primarily depends on the follow-up expansion capability of the specific fastening system.

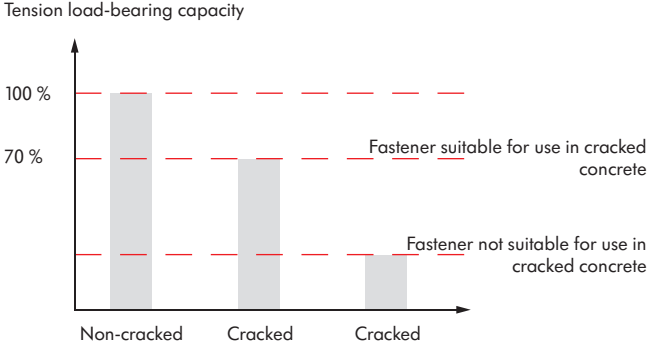


Bild 5.17: Load-bearing capacity of fasteners in non-cracked and cracked concrete

Consequently, fasteners that are not suitable for use in cracked concrete are not approved for use for single fastenings in cracked concrete. Nevertheless, some of these fasteners may be used for redundant fastenings (fastenings with multiple anchorage points) such as ceilings and facades.

5.3 Screw anchors

5.3.1 Installation in concrete

In daily practice screw anchors are installed with electric screw guns (Figure 5.18). However, they can also be installed with a ratchet or a calibrated torque wrench.

Figure 5.18: Installation of a screw anchor with an electric screw gun [10]

The screw anchor is correctly installed if the fixture is pressed against the concrete surface and no easy turning of the fixture is possible. If the torque moment is further increased a sudden steel failure of the screw anchor occurs. For screw anchors with a large core diameter or if the embedment depth is chosen too little compared to the embedment depth stated in the respective approval or in the manufacturer's information shearing-off of the threads cut into concrete may occur.

Therefore, it should not be tried to increase the torque moment higher than the value recommended by the manufacturer if the head reaches the attachment. In the case that the installation is executed with an electrical screw gun it can be assumed that the installation is correct if the head of the screw anchor is flush with the fixture, the fixture is pressed against the concrete surface, and no turning of the socket wrench can be noted. The electrical screw gun can then be turned off and removed from the head of the screw anchor.

Furthermore, when installing screw anchors it must be considered that they can only be used once since the sharpness of the cutting thread decreases if it is used several times. It is intended for single use only. If it is used several times the thread is not cut into the concrete correctly and it is not possible to transfer the complete load into the base material.

Moreover, in Germany it is due to the DIBt [11] not allowed to install a screw anchor twice into the same drill hole since this may lead to the cutting of an additional thread, thus leading to a significant decrease of load to be transferred.

The cutting edge of the used drill bit influences the torque moment necessary for the installation of the screw anchor as well. The maximum possible limits are regulated in the respective approval. For screw anchors with a nominal drill bit diameter of e.g. d_0 = 10 mm a drill bit with a maximum cutting egde of d_{cut} = 10,45 mm should be used according to the approval. Heavily worn drill bits make installation harder since the installation torques according to Figure 5.19 are significantly higher when using a heavily worn drill bit (d_{cut} = 10,0 mm) compared to a new drill bit (d_{cut} = 10,3 mm).

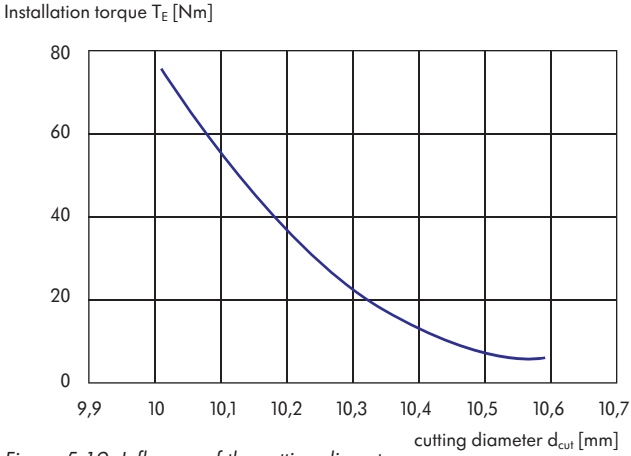


Figure 5.19: Influence of the cutting diameter on the installation torque in concrete [5]

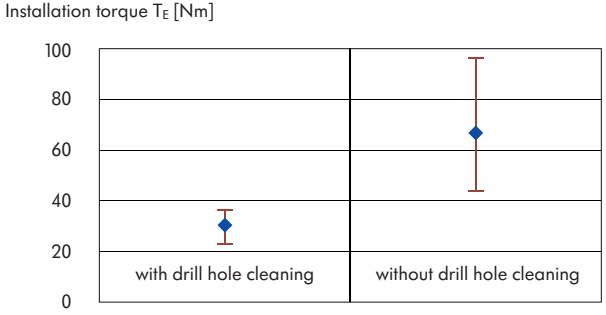


Figure 5.20: Influence of the drill hole cleaning on the installation torque T_E of screw anchors in concrete [5]

The installation torque increases significantly even if the drill hole is not being cleaned (Figure 5.20). The drilling dust is pressed between the wall of the drilled hole and the core of the screw anchor. If the drilled hole is not cleaned there is a risk that the screw anchor is not fully installed into the hole (drill hole depth is reduced by the drilling dust in the drilled hole) and, therefore, the fixture is not pressed against the concrete surface.

5.3.2 Tension loading in non-cracked concrete

As a rule, the failure modes of screw anchors are similar to those of bolt or undercut anchors. At a shallow embedment depth and an entire thread across the complete embedment depth concrete failure occurs for the whole embedment depth (Figure 5.21a). At a larger embedment depth the length of the concrete failure cone is reduced, a combination of concrete failure and pull-out occurs (Figure 5.21b).

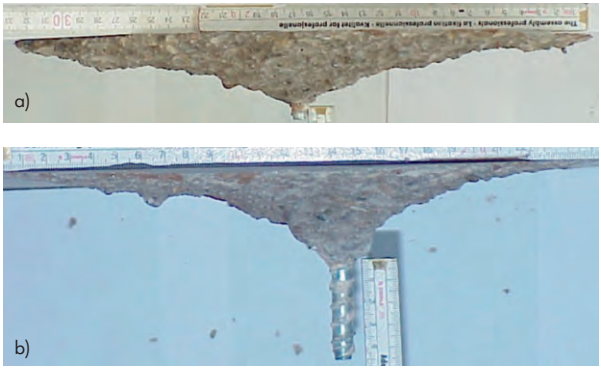


Figure 5.21: Concrete failure at small embedment depth a) h_{nom} = 50 mm and b) h_{nom} = 90 mm [2]

5.3.3 Shear loading in non-cracked concrete

Screw anchors fail like metal expansion and undercut anchors under shear loading.

5.3.4 Combined tension and shear loading in non-cracked concrete

The load-bearing behaviour of screw anchors under combined tension and shear loading in non-cracked concrete is similar to that of metal expansion or undercut anchors.

5.3.5 Tension loading in cracked concrete

Due to the crack in the concrete, the undercut area is reduced compared to non-cracked concrete if screw anchors are installed into cracked concrete. As described in chapter 5.2.4, the medium ultimate load for metal expansion or undercut anchors suitable for use in cracked concrete is reduced by approximately 30 % for crack widths of about 0,3 mm. Moreover, the stiffness of the system is reduced [5]. The load displacement behaviour equals the behaviour schematically displayed in Figure 5.15a.

5.4 Bonded anchors

5.4.1 Tension loading in non-cracked concrete

Figure 5.22 shows typical failure modes for bonded anchors under tension loading. For shallow embedment depths ($h_{ef} \approx 3\,d$ to $5\,d$) cone shaped concrete failure beginning from the end of the fastener occurs (Figure 5.22a). For larger embedment depths a combined failure mode is typically observed. At the edge of the drilled hole a concrete failure cone with a depth of about 2 d to 3 d occurs. Along the rest of the embedment depth bond failure occurs. The bond failure can occur at the boundary between the concrete and the mortar (Figure 5.22b), at the boundary between the mortar and the threaded rod

(Figure 5.22c), or as a mixed failure between the concrete and the mortar along the upper portion of the rod and between the mortar and the threaded rod along the lower portion of the rod (Figure 5.22d). For very large embedment depths the bond is so strong that steel failure occurs (Figure 5.22e). For fastener groups with small fastener spacing a composite concrete failure cone will occur. For fastenings located near to an edge or in a corner concrete edge failure or splitting failure can occur.

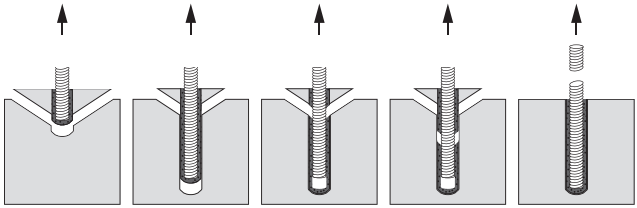


Figure 5.22: Failure modes for bonded anchors under tension loading [12]

Bond strengths strongly depend on the type of mortar. The bond strength is product-dependent and the bond strength determined for one product cannot be applied to other products.
According to [12] bond strength is independent of the diameter of the threaded rod for most products. The bond strength of certain products, however, can be significantly lower for a given rod diameter [13].

The influence of the concrete compressive strength on the bond strength is also product-dependent, however, it is usually relatively small. In general, a bond strength determined in a concrete with strength $f_{ck,cube} \approx 25$ N/mm^2 can be applied for concrete strength

classes up to C50/60. When bonded anchors are used in concrete with even higher strengths the bond strength can decrease due to the very smooth walls of the drilled hole.

The bond strengths given in the product approval are valid for dry concrete and for drilled holes made using a rotary-hammer and carefully cleaned using a combination of brushing and air blasting before installation of the fastener. Furthermore, it is assumed that the concrete is at room temperature and that installation is performed according to the manufacturer's recommendations.

When capsule systems that are intended to be installed using a combined hammering and rotating motion for the threaded rod are installed by hammering alone, the mortar will not be sufficiently mixed and will not cure completely. This can result in very low pull-out loads.

Independent of the setting direction (vertically down, vertically up, horizontal) concrete dust will remain on the wall of the drilled hole if it is not properly cleaned. The hole cleaning can have a small or a large influence on the load-bearing capacity depending on the fastening product. Capsule systems that are installed using a combined hammering and rotating motion are typically less sensitive to the hole cleaning because the dust on the drilled hole wall is mixed into the mortar as the fastener is rotated. The reduction of the ultimate load is typically ≤ 20%.

For injection systems, the reduction of the ultimate load as a function of the hole cleaning depends on the mortar that is used, i.e. the bonding properties. The reduction of the ultimate load is product-dependent and can be as large as 60 % [14] (Figure 5.23). With injection systems it is very important that the drilled hole is cleaned with a suitable brush because air bursting the hole clean with the typical hand pump alone does not sufficiently remove the drilling dust from the hole.

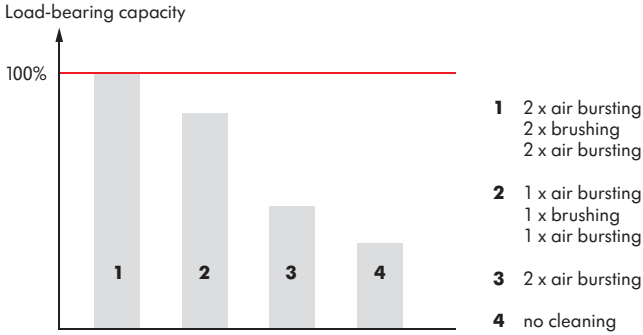


Figure 5.23: Influence of the degree of hole cleaning on the ultimate load of M12 injection anchors in dry concrete (after [14])

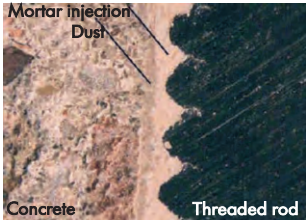


Figure 5.24: Example of poor hole cleaning for an injection anchor [13]

An effective hole cleaning is particularly difficult in water-saturated concrete because the drilling dust sticks to the wall of the drilled hole. Furthermore, depending on the type of mortar used, the water along the wall of the drilled hole can have a negative effect on the bond strength. In wet concrete the load-bearing behaviour depends on the resin used in the mortar.

With capsule systems based on unsaturated polyester resin or vinyl ester resin containing styrene the reduction of the pull-out load in wet

concrete is ≤ 20% and thus relatively small. With other resin systems, e.g. vinyl ester resin without styrene or epoxy resin, the reduction of the ultimate load can be much larger. Depending on the type of resin used, this reduction of the ultimate load for injection systems in wet concrete can be amplified if the drilled hole is not properly cleaned. Even when a drilled hole is properly cleaned, if standing water is present, the bond strength will be reduced. The bond strength is comparable to that in water-saturated concrete when adequate hole cleaning is performed.
Bond strength reduces with increasing temperature. This behaviour is product-dependent. The bond strength of a bonded anchor based on unsaturated polyester resin at 80 °C is about 0,7 times the value at 20 °C. At even higher temperatures the strength drops rapidly because the glass transition temperature is reached. Mortars based on vinyl ester also have a bond strength at 80 °C that is about 0,7 times the value at 20 °C. If the temperature further increases, the strength is reduced, however, less than with polyester resin. Bonded anchors based on epoxy resin typically show a reduction of the bond strength with temperature that is more significant than that for the other types of resin discussed above. However, the reduction is very sensitive to the resin formulation.

5.4.2 Shear loading in non-cracked concrete

Under shear loading bonded anchors fail in a similar manner to undercut and metal expansion anchors.

5.4.3 Combined tension and shear loading in non-cracked concrete

The load-bearing behaviour of bonded anchors in non-cracked concrete under combined tension and shear loading is similar to that of undercut and metal expansion anchors.

5.4.4 Tension loading in cracked concrete

Bonded anchors located in cracked concrete fail by steel failure or pull-out depending on the embedment depth, concrete strength, and steel strength. When pull-out occurs, the bond usually fails between the mortar and the wall of the drilled hole. In limited cases failure can also occur between the mortar and the threaded rod. For fastenings with small edge distances or fastenings located in thin building components splitting may also occur. Concrete cone failure is not typically observed.

Figure 5.25 shows schematic load-displacement curves for bonded anchors located in cracked and non-cracked concrete. The stiffness of bonded anchors located in cracked concrete is less than in non-cracked concrete, as is the case with other types of fasteners. After the bond strength between the mortar and the drilled hole wall is exceeded, the threaded rod begins to pull out with the surrounding mortar.

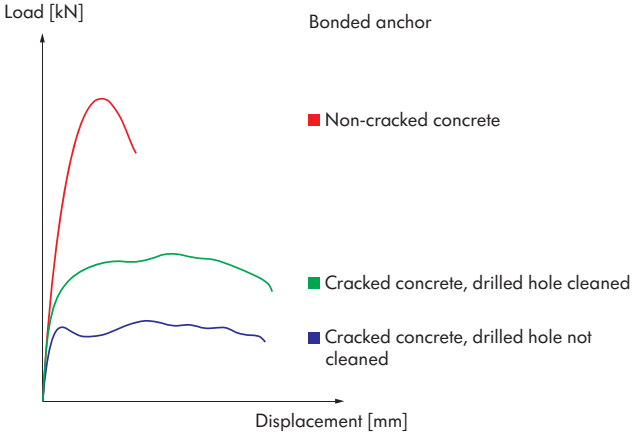


Figure 5.25: Load-displacement curves for bonded anchors in non-cracked and cracked concrete (schematic) [15]

A load increase is still possible after this occurs (green curve in Figure 5.25). The increase in load is due to the friction between the mortar and the unevenly drilled hole wall. Because the friction depends on the random unevenness of the hole wall, it varies greatly. This can result in highly irregular load-displacement behaviour after the initial bond strength is exceeded.

If the drilling dust is not carefully removed from the drilled hole the ultimate load will be further reduced (blue curve in Figure 5.25). The influence of the hole cleaning on the pull-out load is product-dependent and typically more severe in cracked concrete than in non-cracked concrete [16].

When a bonded anchor is located in a crack and loaded by a constant tension load, the displacement of the fastener will increase if the crack is repeatedly closed and opened to the initial width. If the constant tension load is much smaller than the load that exceeds the bond strength between the mortar and the concrete, only a small increase in displacement will occur. If the load is higher, however, the fastener can be pulled out after a few crack opening and closing cycles.

Due to the high tension strength of the mortar, a crack will tend to run between the drilled hole wall and the mortar, i.e. not through the mortar. This destroys the bond between the mortar and the wall on one side (Figure 5.26). If one assumes that the crack shown in Figure 5.26 extends along the entire embedment depth of the fastener then the ultimate load after the bond strength is exceeded is theoretically 50 % of that in non-cracked concrete.

The pull-out loads of bonded anchors in cracked concrete are significantly lower than in non-cracked concrete. For a crack width of w = 0,3 mm the values range between 25 % and 80 %, i.e. 50 % on average, of the values in non-cracked concrete.

Due to the significant reduction of the ultimate load in cracked concrete common bonded anchors are usually not approved in Europe for use in cracked concrete.

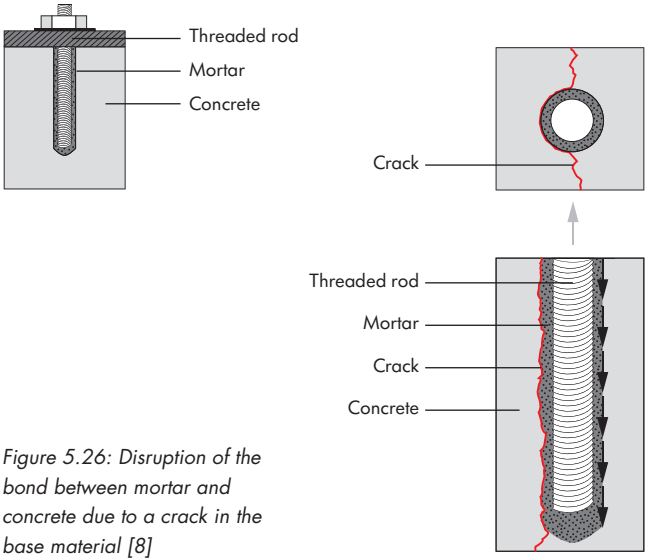


Figure 5.26: Disruption of the bond between mortar and concrete due to a crack in the base material [8]

5.4.5 Shear loading in cracked concrete

In general, cracks have only a small influence on the stiffness of bonded anchors loaded in shear. When the edge distances are large and the embedment depth is sufficient, steel failure will occur. In this case, the ultimate load is not significantly influenced by the crack. Concrete edge failure will occur for fasteners located near to an edge.

5.4.6 Combined tension and shear loading in cracked concrete

The load-displacement behaviour of bonded anchors in cracked concrete is basically the same as in non-cracked concrete.

5.5 Bonded anchors suitable for use in cracked concrete

5.5.1 Non-cracked concrete

In non-cracked concrete the load-bearing mechanism, load-displacement behaviour, and the failure modes of bonded-expansion anchors loaded in tension do not differ significantly from ordinary bonded anchors. The expansion forces tend to have a beneficial effect on the behaviour. The drilled hole cleaning has a relatively small influence on the load-bearing behaviour because after the bond between the mortar and the drilled hole wall is exceeded the anchor functions as an expansion anchor. The load-bearing behaviour under temperature loading and sustained loading as well as the behaviour in response to other environment conditions is the same as for ordinary bonded anchors (see Section 5.4.1).

Bonded-expansion anchors behave similarly to metal expansion anchors under shear loading.

5.5.2 Cracked concrete

Figure 5.27 shows load-displacement curves for bonded-expansion anchors without pre-tensioning located in cracked and non-cracked concrete. The stiffness and ultimate load are reduced in cracked concrete, as is the case for expansion anchors suitable for use in cracked concrete.

With bonded-expansion anchors, cracks effect the bond the same way as with ordinary bonded anchors. The bond between the mortar and the drilled hole wall on one side is destroyed by the crack. As the fastener is loaded, the mortar expands radially as the anchor bolt is pulled into the mortar shell (Figure 5.28).

The fastener undergoes follow-up expansion and bridges the crack opening. The follow-up expansion can be observed in Figure 5.27 as a change in the slope of the load-displacement curve. Expansion forces are generated, which in-turn create friction forces between the mortar and the wall of the drilled hole. The friction forces are suffic-

ient to resist the applied tension load without the contribution of the bond between the mortar and the hole wall. If the force required to free the anchor bolt from the mortar is small enough, bonded-expansion anchors will undergo expansion even in poorly cleaned drilled holes. Thereby, the same ultimate load is reached as in well cleaned holes (Figure 5.27).

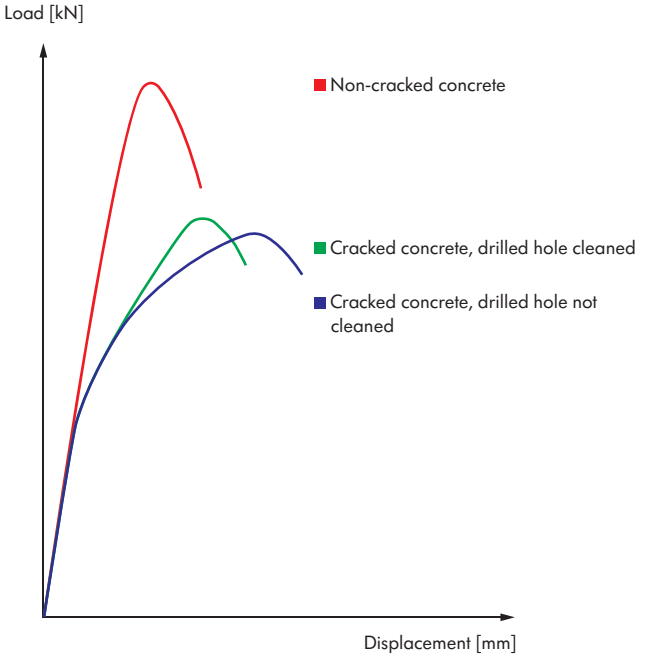


Figure 5.27: Load-displacement curves for bonded-expansion anchors in non-cracked and cracked concrete (schematic) [8]

Bonded-expansion anchors located in cracked concrete fail in response to the anchor bolt being pulled through the mortar. The ultimate loads are about 30 % lower than in non-cracked concrete. The design of fastenings with bonded anchors suitable for use in cracked concrete can be performed according to the CC-Method.

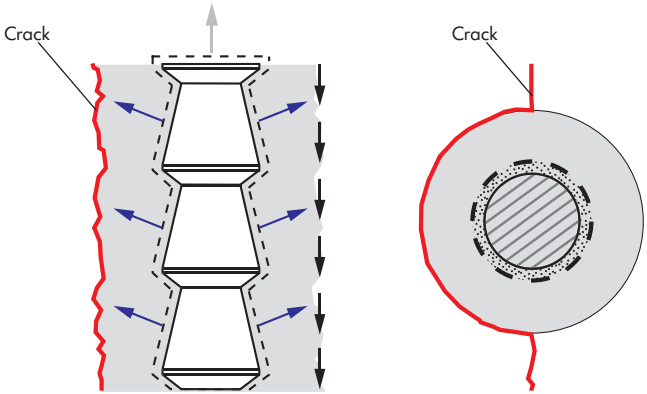


Figure 5.28: Disruption of the bond between mortar and concrete due to a crack in the base material and tension load transfer for bonded-expansion anchors [8]

5.6 Plastic anchors

5.6.1 General

Load transfer with plastic anchors is made possible by inserting a special expansion element (screw or nail) into the plastic sleeve of the fastener. This displaces the plastic and presses the sleeve against the wall of the drilled hole. Expansion forces are generated along the axis of the fastener. Modern plastic fasteners are designed to produce a constant distribution of the expansion forces along the axis of the fastener.

When a screw is used as the special expansion element, a thread is stamped into the sleeve as the screw is inserted. External tension forces are transferred from the screw to the sleeve by mechanical interlock and friction. The forces are then transferred from the sleeve to the base material by friction between the sleeve and the wall of the drilled hole. When a nail is used as the special expansion element, driving of the nail displaces the sleeve. In this case, applied tension loads are primarily transferred to the sleeve by friction. As the duration of the load increases the plastic sleeve creeps to better match the uneven surface of the drilled hole wall and fills the micro-pores in the concrete. This generates mechanical interlock at the microscopic scale and thus a better fit between the fastener sleeve and the base material.

Plastic anchors that use a screw as the special expansion element typically fail by pulling the sleeve out of the drilled hole. The base material is not damaged by this process. Plastic anchors that use a nail as the special expansion element may additionally fail by pulling the nail out of the sleeve as a result of insufficient friction between the nail and the sleeve. Experience has shown that the polyamides PA6 and PA6.6 are well-suited for the production of the sleeves for plastic anchors. Polyamides are semi-crystalline thermoplastics, the material properties of which are influenced by several parameters. Moisture content, temperature, and time are relevant parameters for the load-bearing behaviour of plastic anchors.

The volume of the polyamides PA6 and PA6.6 changes with the amount of absorbed water. As the moisture content increases the material toughens while the hardness and stiffness are reduced. The material reacts similarly to changes in temperature. As temperature increases the stiffness and strength is reduced.
Furthermore, the load-bearing behaviour of plastic fasteners is strongly influenced by the time-dependent, visco-elastic deformation behaviour of the plastic sleeve, i.e. creep, and relaxation play key roles.

5.6.2 Load-bearing behaviour of plastic anchors in concrete

The pull-out load of a plastic anchor depends on the expansion force it can generate. The magnitude of the expansion force is influenced by the fastener design. Therefore, the allowable loads for approved plastic anchors produced by different manufacturers vary.

5.6.3 European technical approvals

Plastic anchors which are tested according to the European guideline ETAG 020 and which have a European technical approval (ETA) are approved for multiple use of so-called non load-bearing systems in concrete or masonry. In case of multiple use the fastened fixture is designed such that the load can be transferred to adjacent anchors if a plastic anchor fails e.g. due to excessive slip or failure. Generally, non load-bearing system means that 'only' the fastened fixture falls down but not that the complete building crashes if the fastening fails.
The ETA's contain characteristic resistances for the various base materials in the approvals. Depending on the base material different safety factors have to be taken into account. Moreover, the specified resistance values are only valid for the stones stated in the ETA. Divergences are only possible for bigger stones with the same geometry and higher compressive strengths. If the stones differ otherwise job site tests have to be executed. However, this is only possible if similar stones are already included in the ETA.

The characteristic resistances stated in the ETA are valid for tension, shear, and combined tension and shear load under any angle. There is no restriction with regard to mere tension forces. It has to be considered that the stated characteristic resistances do not correspond with the admissible loads. The loading of a fastener with its characteristic resistance value can lead to its premature failure!
The ETA also regulates the allowed drilling method for the respective anchorage surface. If it is not complied with, job site tests have to executed. This is also valid if the stated embedment depth stated in the ETA is not adhered to.

5.7 Injection anchors in masonry

Injection anchors transfer tension loads to hollow masonry units primarily by mechanical interlock that is generated by the mortar occupying the void spaces in the units. Additionally, bond resistance is present in the regions of the intersected webs of the unit. Injection anchors typically fail due to failure of the masonry unit. Therefore, the ultimate load of the fastener depends on the strength of the unit as well as on the number of webs intersected by the fastener. Furthermore, the load-bearing capacity can be influenced by the strength of the mortar. If the mortar strength is too low, the threaded rod may be pulled out of the mortar before failure of the masonry unit occurs.

In solid masonry units, voids (e.g. lifting holes) are not typically intersected during drilling. Thus, the fastener transfers load by bond between the wall of the drilled hole and the mortar. This is also valid for hollow units if no voids are intersected during drilling. The load-bearing capacity is strongly influenced by the cleaning of the drilled hole during installation. Therefore, the manufacturer's recommendations for cleaning of the drilled hole must be observed. In solid masonry units, injection anchors typically fail due to bond failure between the mortar and the wall of the drilled hole.

Drilling with a rotary-hammer causes a funnel-shaped failure where the drill bit exits the masonry web (Figure 5.29 left). The web thickness is thereby reduced compared to drilling with rotary motion only. This in-turn reduces the ultimate load. Therefore, the allowable loads are dependent on the drilling method and mentioned in the approvals.

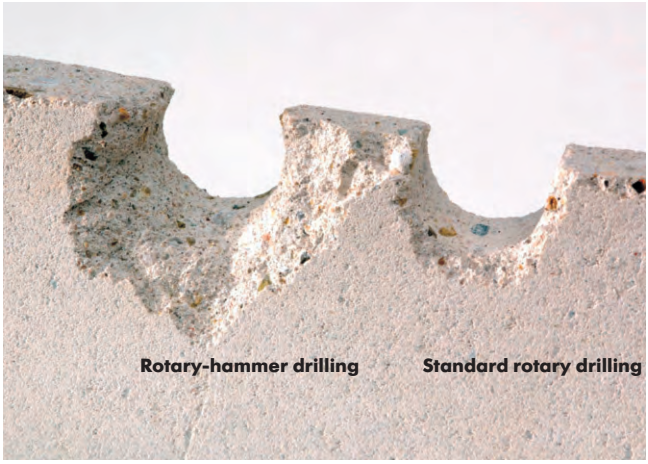


Figure 5.29: Influence of the drilling method on the hole geometry in limestone units

If no voids are intersected during drilling in hollow masonry units and for fastenings in solid masonry units, injection anchors transfer load by bond between the mortar and the wall of the drilled hole. The bond strength depends strongly on the cleaning of the drilled hole. Figure 5.30 shows the influence of the cleaning of the drilled hole on the ultimate loads of injection anchors located in solid limestone units.

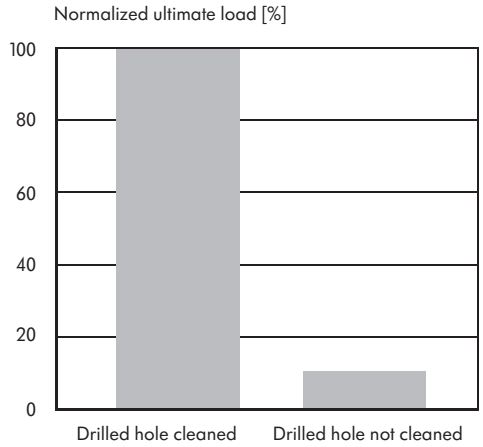


Figure 5.30: Influence of the cleaning of the drilled hole on the normalized ultimate load of injection anchors located in solid masonry [18]

6. Fastenings of sunblinds

6.1 General

Since March 2006 the DIN EN 13561 „External blinds – Performance requirements including safety" is valid. It regulates the requirements with regard to the usability of sunblinds and their CE marking. It is valid for folding arm awnings, trellis arm awnings, pivot arm awnings, slide arm awnings, vertical roller awnings, marquisolettes, façade awnings, skylight awnings, conservatory awnings, Dutch awnings, and insect screens in case they were produced after the date of issue of the norm.

Figure 6.1: Securely fastened sunblind

6.2 Indications in the norm regarding fastening technology

The subitem 17„Handling and storage“ comprises the following indications with regard to fastening:
17.3 Performance requirement: „... Any special equipment for assembly, fixing, and setting, e.g. appropriate fixing brackets, shall be provided ...“

Moreover, subitem 18 „Information for use“ specifies requirements to be fulfilled by the instruction.
18.3.2.1 General instructions: „...The instructions shall include step by step guidance on the correct sequence of operations to achieve a proper good and safe installation, e.g. instructions for assembly, installation, and fixing...“

The standard does not specifiy further regulations regarding the fastening of sunblinds to the building object.

6.3 Existing guidelines

The “Industrieverband Technische Textilien-Rollladen-Sonnenschutz e.V – ITRS” (the former “BKTex Bundesverband Konfektion Technischer Textilien e.V.”) developed guidelines for fastenings of folding arm awnings for the German market. Due to lacking European regulations the solution of the ITRS will be shown in the following since it proved to be very good in practice. These guidelines (only available in Germany) include explicit substantiation:

- „Richtlinien zur technischen Beratung, zum Verkauf und zur Montage von Gelenkarmmarkisen“ (January 2008)
- „Sicherheitshinweise in Montage- und Bedienungsanleitungen für Markisen“ (January 2006)
- „Windlasten zur Konstruktion von Abschlüssen und Markisen im eingefahrenen Zustand“ (May 2008)

This guideline describes the correct procedure with regard to the installation of a sunblind. Moreover, it includes calculation methods for the determination of tension loads of fasteners. In addition, the guideline recommends suitable products for the installation.
The guidelines can be purchased from the ITRS (www.itrs-ev.com).

6.4 Requirements for the fastening systems, especially corrosion protection

For the fastening of sunblinds only fastening systems with a general technical approval or European technical approval may be used. Concerning fastenings in masonry the IRTS guideline determines in which way a divergence from the approvals is allowed. However, basically an injection system with an approval must be used. The divergences only refer to the loads and some parts of the system. The use of the parts explicitly stated in the guildeline was proven by the said manufacturers in detail.

In addition, the guideline revised in January 2008 includes an accurate definition of the requirements with regard to corrosion protection of the fasteners when used for the installation of sunblinds. It is generally valid for fastener approvals that prescribe at least stainless steel with A4 quality to be used. In the case of high chemical exposure or exposure in sea water even highly corrosion-resistant steel with the material number 1.4529, so-called HCR steel, must be used.
For use in the current guideline a precise definition was compiled that defines under which preconditions galvanized steel is sufficient for outdoor applications and when stainless steel must be used. These examinations were undertaken especially for the practical use in combination with folding arm awnings. Since folding arm awnings need to be maintained on a regular basis due to their construction it was decided that the fastenings should also be checked during the maintenance with regard to starting corrosion. If the fasteners are regularly

checked it is possible to use fasteners made of galvanized steel for exterior applications. However, this regulation was restricted to an installation height of 8 m above terrain. Moreover, a protective cover like e.g. a canopy, eaves, or something similar is necessary in order to avoid the fastening being directly exposed to wind and weather.

The rigorous reglementation of the fastener applications for facades ventilated from behind was also included in the guideline. In this case of application it is not possible to check the fastening for possible corrosion. For fastenings close to industry or to the sea the rigorous regulations of the fastener applications were also taken over. In these cases it is also mandatory to use stainless steel.

6.5 Calculation basis for the load existing at the fastener

In order to calculate the loads existing at the fastener according to the guideline the dead load of the sunblind and the loading due to wind are taken into consideration. Therefore, the manufacturers of sunblinds classify their sunblinds into one of four classes of wind resistance within the scope of the CE marking as a basis for the determination of the action of wind. Further loads are not taken into account.

6.6 Requirements to be fulfilled by the installer

The installer has to fasten the sunblind in a secure way. According to the guideline he must be able to assess the base material regarding its load-bearing capacity in order to do so. His knowledge consequently enables him to choose the necessary number of the right kind of consoles and a suitable fastening system for this specific base material.
If the calculated load cannot be transferred into the base material due to the action of wind that is too high (e.g. because the load-

bearing capacity of the existing wall is not sufficient) the installer has to reduce the class of wind resistance depending on the load to be transferred into the base material and calculate the load again. This means that he has to point out to his customer in writing that the class of wind resistance had to be reduced because of the fastening in the base material and that the sunblind needs to be closed at a reduced action of wind.

6.7 Insulated base materials

Especially in the case of subsequent fastenings of sun protection measures it is very often the case that the base materials were equipped with an additional insulation. Even highly insulated masonry (without additional insulation) always comprises insulation in the concrete ceiling. The insulation layer must be bridged in a pressure-resistant way in order not to be damaged and to ensure the transfer of loads into the base material respectively clamp the fixture against the base material. If the position of the fastening is already known before the insulation is installed it is possible to dowel e.g. a console for the installation directly onto the base material.
However, if the decision of subsequently installing a sunblind is being made after the insulation was attached it is possible to use the Würth Amo-Max system (Figure 6.2). In this system the insulation is bridged with an aluminium sleeve. In order to balance out the different thicknesses of the plaster layers washers are offered. It is important to pay attention to the correct length of the fastening system when dealing with this kind of installation since an insulation layer and an existing plaster layer do not tranfer any loads.

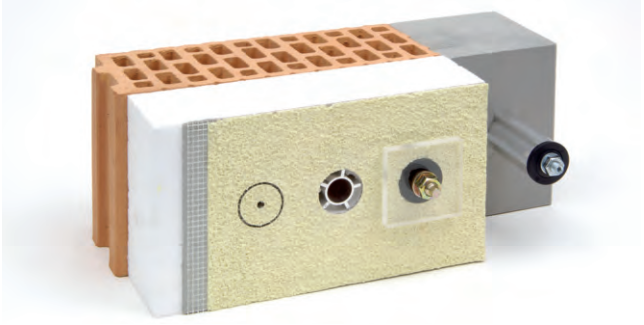


Figure 6.2: Schematic model of the Amo-Max system

7. Aspects of selecting a suitable fastener

7.1 General

Many different fastening systems are available to create connections in structures. The user may sometimes have difficulty choosing a suitable fastening system for an application from the wide variety of available products.

Optimized fastening systems are available for different applications depending on the type of base material (concrete, masonry) and its geometry, on the loading, on the field of application, and on the type of installation. Because of the large variety of available fastening systems the user must know the admissible service conditions and the functioning principles of different fastener types. He has to consider the advantages and disadvantages of the various systems.

Essential aspects for choosing a suitable fastener for a given application are summarized in Figure 7.1.

Criteria for choosing a suitable fastener

Safety relevance	Anchorage material and geometry	Loading	Environment	Installation	Additional considerations
Part of the load-bearing construction	Concrete	Magnitude	Temperature	Single or multiple use	Safety in case of fire
Danger for humans	Masonry	Direction - Tension - Shear - Incline tension	Moisture	Pre-positioned installation	Economy
Potential for significant economic loss	Lightweight materials		Interior or exterior	In-place installaton	Availability
	Dimensions		Corrosion	Stand-off installation	
	Edges	Type - Static - Dynamic			

Figure 7.1: Aspects of choosing a suitable fastener

7.2 Safety relevance

Fastenings which could endanger human life or result in significant economic loss if failure occurs are called fastenings with safety relevance (Figure 7.2, [19]). In general, fastenings for load-bearing parts of a construction are safety relevant. Design by an engineer and professional installation is needed for these types of fastenings.
If the service conditions in a structure differ significantly from the admissible service conditions in a fastener product approval, an approval in individual cases on the basis of the assessment of a surveyor might be possible.
Fastenings with only a small probability of endangering human life are not safety relevant [19]. Installation is performed according to accepted rules of workmanship. Design is not necessary.

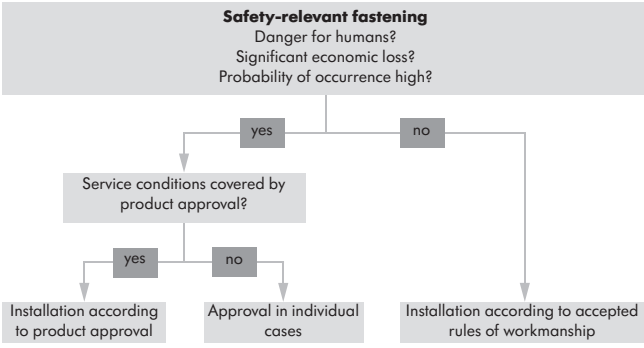


Figure 7.2: Rules for the execution of a fastening

7.3 Base material and geometry of member

7.3.1 General

The range of suitable fasteners is mainly influenced by the type and strength of the base material. For fastenings in normalweight concrete, metal anchors, bonded anchors, and plastic anchors are appropriate. In masonry units, plastic anchors and injection anchors are applicable.

Table 7.1 shows an overview of approved and recommended fasteners in different base materials. Details on the fastening systems can be found in chapter 4.

Base material			Type of fastener				
			Metal anchors and undercut anchors	Bonded anchor (capsule)	Bonded injection anchor (with mesh tube)	Bonded injection anchor (without mesh tube)	Plastic anchor
Normalweight concrete			■	■		■	■
Masonry	Clay	Solid brick			■ [1)]	■	■
		Perforated brick			■		■
	Sand-lime brick	Solid brick			■ [1)]	■	■
		Perforated brick			■		■
	Lightweight concrete	Solid brick				□	■
		Perforated brick			■		■
	Normalweight concrete	Perforated brick			■		■
Autoclaved aerated concrete			■		■	■	■

■ Approved system available □ Recommended by the manufacturer [1)]Recommended because of grip opening

Table 7.1: Approved and recommended fasteners for different base materials (concrete and masonry)

7.3.2 Fastenings in normalweight concrete

To choose a suitable fastener for applications in normalweight concrete one must consider the static system (statically determinated or redundant), the condition of the concrete (cracked or non-cracked), and the function of the component that has to be fastened (load-bearing or non load-bearing).

A system is statically determinated if its internal load distributions can be determined using equilibrium equations alone, i.e. without the need for deflection and stiffness criteria. Examples of simple statically determinated and indeterminated (redundant) systems are given in Figure 7.3. A fastening point can consist of a single fastener or a group of fasteners. The failure of a fastening point in a statically determinated system can cause failure of the complete construction. Therefore, reliable fasteners for single use have to be used in such cases.

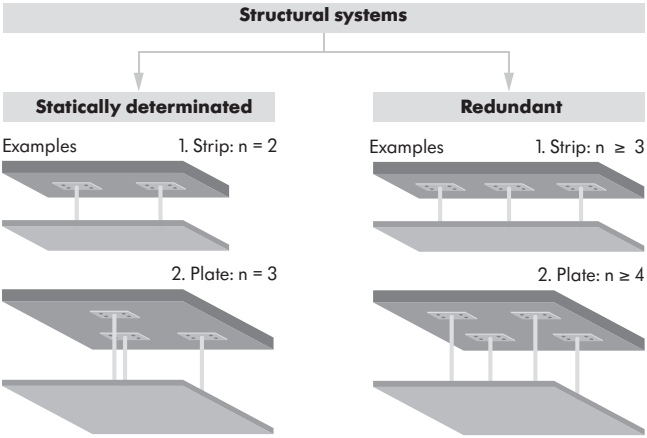


Figure 7.3: Definition of structural systems

These fasteners have to be able to transfer loads reliably into the base material. In the case of redundant static systems or non-structural applications, fasteners for multiple use can be used. Redundant systems are systems in which the load can be transferred to an adjacent fixing point in the case of failure of one fastener. However, this kind of fastening is only allowed for minor loads to be transferred (e.g. suspended ceilings).
A part of a structure is considered to be load-bearing if it is required for the transfer of structural loads. For example, a foundation pile is a load-bearing element, whereas an electrical conduit is not.
A flowchart for the choice of an appropriate fastener is shown in Figure 7.4.

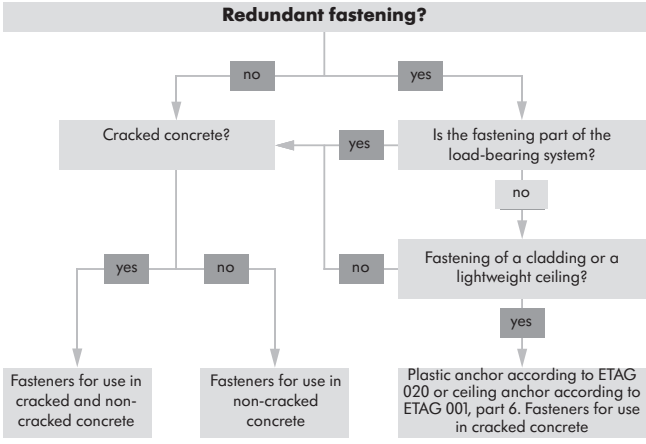

Redundant fastening?
no
yes
Cracked concrete?
yes
Is the fastening part of the load-bearing system?
no
yes
no
no
Fastening of a cladding or a lightweight ceiling?
yes
Fasteners for use in cracked and non-cracked concrete
Fasteners for use in non-cracked concrete
Plastic anchor according to ETAG 020 or ceiling anchor according to ETAG 001, part 6. Fasteners for use in cracked concrete

Figure 7.4: Flowchart for the selection of a suitable fastener in normalweight concrete

For statically determinated systems or for structural applications it must be considered whether the concrete is cracked or non-cracked (see Figure 7.5 or Section 2.2.5). In general, cracked concrete has to be assumed because stresses generated by applied loads or temperatures often exceed the tensile strength of concrete. To assume that the concrete is non-cracked, Equation (8.1) must be shown to be valid. For this verification basic knowledge in the design of reinforced concrete structures is needed.

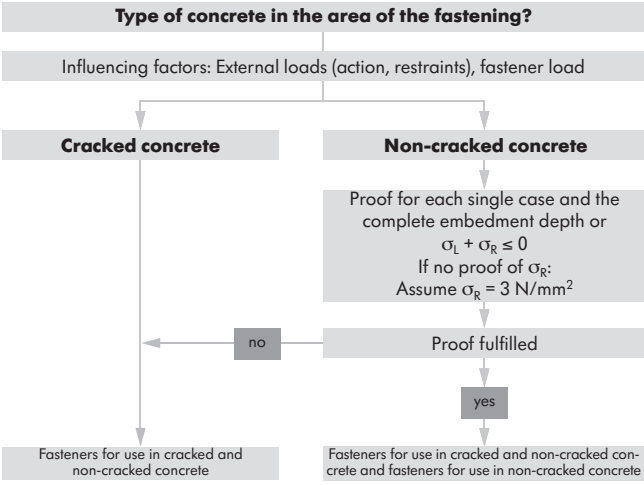

Type of concrete in the area of the fastening?
Influencing factors: External loads (action, restraints), fastener load
Cracked concrete
Non-cracked concrete
Proof for each single case and the complete embedment depth or
$\sigma_L + \sigma_R \leq 0$
If no proof of σ_R:
Assume $\sigma_R = 3$ N/mm²
no
Proof fulfilled
yes
Fasteners for use in cracked and non-cracked concrete
Fasteners for use in cracked and non-cracked concrete and fasteners for use in non-cracked concrete

Figure 7.5: Flowchart for the selection of a suitable fastener in normalweight concrete

The fastening of claddings or lightweight ceilings can be realized with ceiling anchors for use in cracked concrete (Figure 7.6). The design has to be carried out according to the details in the approval. For cladding constructions, plastic anchors are also possible.
In general, applications for fasteners in high-strength concrete (> C50/60) do not have an official approval.

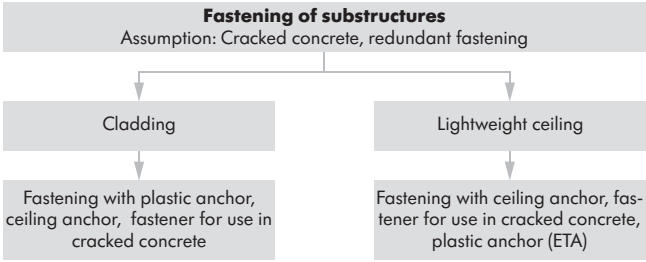

Fastening of substructures
Assumption: Cracked concrete, redundant fastening
Cladding
Lightweight ceiling
Fastening with plastic anchor, ceiling anchor, fastener for use in cracked concrete
Fastening with ceiling anchor, fastener for use in cracked concrete, plastic anchor (ETA)

Figure 7.6: Fasteners for substructures

7.3.3 Fastenings in masonry units

The type of brick (perforated brick or solid brick) and the material of the masonry unit (clay, limestone, normalweight concrete, lightweight concrete, or autoclaved aerated concrete) influence the choice of fastener. If the masonry unit does not fulfil the requirements in terms of its strength, gross density, or format as well as the requirements for installation (e.g. type of drilling), the admissible load has to be calculated from the results of on-site tests (see Chapter 8).

7.4 Characteristic fastener spacing, edge distance and member thickness

For all fastener applications the minimum fastener spacing and edge distances must be maintained to avoid splitting of the base material during installation (Figure 7.7) and to guarantee the admissible load capacity. The fastener spacing given in the product approvals depends on the splitting force generated by the fastener [20]. Fastening systems that generate small splitting forces, such as undercut or bonded anchors, normally have smaller allowable fastener spacing compared to expansion anchors. Therefore, fasteners that generate small splitting forces are more suited for applications in thin or narrow concrete members.
During installation calibrated torque wrenches should be used and the installation torque recommended should be applied.

Figure 7.7: Splitting cracks due to installation of a torque-controlled expansion anchor in concrete, edge distances smaller than the specified value and/or applied torque larger than the specified value

7.5 Loading

Fasteners can be loaded by tension, shear, or combined tension and shear loads (see Section 3.1). These loads may be static or can vary with time. Different fastening systems may be suitable for some types of loading but not for others. The manufacturer's recommendations should always be consulted when selecting a fastener for a given loading situation.

7.6 Environmental conditions: Temperature

The service conditions with respect to temperature must be observed for fastenings. There are no restrictions concerning temperature for metal anchors. Plastic and bonded anchors, however, are normally limited to applications where the sustained temperature (long-term temperature) is between - 40 °C and + 50 °C. As a rule, temperatures with a short duration are allowed up to a limit of + 80 °C. For some products even higher temperature ranges are allowed. Applications under other thermal conditions and eventual reduction of the admissible load must be checked for each specific application (approval).

7.7 Environmental conditions: Moisture

Moisture in the base material can cause a significant decrease of the failure load for bonded anchors and plastic anchors.
Fasteners with product approvals account for this reduction in the admissible load [8].

7.8 Environmental conditions: Corrosion

Fasteners galvanized with a zinc layer are suitable only for applications in interior spaces because the zinc layer does not offer a permanent protection against corrosion in exterior spaces.
Corrosion must be considered for humid interior spaces and for exterior spaces. Fasteners made of non-corrosive steel should be applied in these situations. One exception is that plastic anchors with galvanized steel screws may be used in exterior spaces as well as in spaces close to industry or to the sea if the screw head is protected from moisture. This protection can be achieved by painting the screw head and the region between thread and anchor shaft.
If the application for the fastener is planned in a very aggressive corrosion environment, non-corrosive steel A4 is not sufficient. High corrosion-resistant steels have to be used in areas with high concentrations of chloride or sulphur dioxide (e.g. indoor swimming pools, constructions close to the sea, and road tunnels). In order to choose a sufficiently high corrosion-resistant steel the steels and their compositions are defined by material numbers and classified into resistance classes with regard to their corrosion resistance.

Material number	Corrosion resistance class / requirements	Typical applications
1.4003 1.4016	I / minor	Dry internal conditions
1.4301 1.4541 1.4318 1.4567	II / moderate	Accessible constructions without considerable concentrations of chlorides and sulphur dioxides
1.4401[4)] 1.4404 1.4571[4)] 1.4439	III / medium	External atmospheric exposure or exposure in permanently damp internal conditions. Unaccessible constructions[1)] with moderate concentrations of chlorides and sulphur dioxides
1.4539 1.4462 1.4565 1.4529 1.4547	IV / strong	Constructions with high concentrations of chlorides and sulphur dioxides (also for build-up concentrations of the pollutants, e.g. fixtures in sea water, in road tunnels) Indoor swimming pools: Please refer to footnotes[2)3)]

[1)] Constructions are considered unaccessible if their state cannot be controlled or if it can only be controlled under aggravated conditions and if these constructions can only be refurbished with the utmost effort in case of need.

[2)] Steel with the material number 1.4539 for fixtures in indoor swimming pool atmosphere without cleaning of the steel and the water according to drinking water ordinance on a regular basis.

[3)] Steels with the material numbers 1.4565, 1.4529, and 1.4547 for fixtures in indoor swimming pool atmosphere without cleaning of the steel and the water containing chloride salt (e.g. salt brine water).

[4)] These steels are also referred to as A4 steels.

Table 7.2: Corrosion-resistant steels and their applications approved in Germany according to the German DIBt [21] as an example

7.9 Installation

The tolerances associated with drilling (drift of the drill bit on the surface of the base material) can cause installation problems for fastener groups. Therefore, in-place installation is preferred for fastener groups because the drill hole can be generated through the clearance hole of the fixture.
The fixture (thickness, clearance hole, etc.) as well as the fastener (anchor length etc.) have to be adapted depending on the type of installation. Fastening systems with a technical approval have markings to help guarantee the required expansion force and embedment depth. By means of this, the aspired embedment intensity and the required embedment depth shall be guaranteed. Installation mistakes, such as insufficient thread length for the nut, can be eliminated if these markings are observed.

7.10 Economy

In addition to the technical aspects mentioned above, economic aspects must be considered when selecting a suitable fastener. Details on this topic are provided in Chapter 11.

8.1 Design concepts

8.1.1 General

It is vital that safety-relevant fastenings are designed by an engineer with knowledge in the field of fastening technique. The design must be based on calculations that can be checked and construction drawings must be made.

Design concepts based on recommendations of the manufacturer, application-specific guidelines as well as national and European design provisions exist for fastenings. These concepts are categorized according to those that use global safety factors and those that use partial safety factors (Section 8.1.2). Concepts with partial safety factors are more widely used because the scatter and the uncertainties related to the materials and the applied actions (constant loads and variable loads) as well as influences due to installation can be considered more accurately by splitting the global safety factor into partial safety factors.

Technical terms used for the explanation of the design concepts are summarized in Table 8.1.

Ultimate load	Maximum load measured in a test (Figure 8.1).
Average ultimate load	Average value of the measured ultimate loads in test series (Figure 8.2).
5 %-fractile	A statistical value that indicates with a defined confidence level (for fastener approvals the confidence level is 90 %) that only 5 % of the individual values of a test series will be less than a defined limit (Figure 8.2).
Characteristic resistance	Corresponds for fasteners to the 5 %-fractile of the peak loads for a given failure mode and load direction.
Design value of the resistance	Corresponds to the characteristic resistance divided by the partial safety factor for the resistance. $R_d = R_k/\gamma_M$
Admissible load	The load by which a fastener may be loaded under the existing service conditions. Safety factors are included in this value. In the European technical approvals an operating life of 50 years is assumed. Admissible loads are sometimes also called service loads.
Recommended load	Admissible load recommended by the manufacturer. Normally not covered by product approvals.

Table 8.1: Definition of technical terms

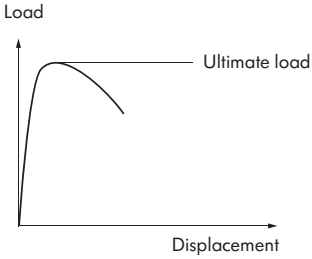


Figure 8.1:
Load-displacement curve with peak load

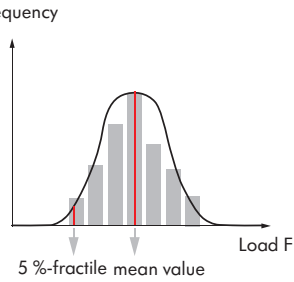


Figure 8.2:
Mean value and 5 %-fractile in a frequency diagram

8.1.2 Design using partial safety factors

For design using partial safety factors the applied action is compared with the resistance of the fastening. The applied action corresponds to the loading on the fastening. It can be classified in terms of the type and the direction of the action (see Chapter 3). The resistance of a fastening describes the load that the fastener or base material can bear. The resistance depends on the type of fastening system and the base material. Figure 8.3 shows a flowchart for the design method with partial safety factors.

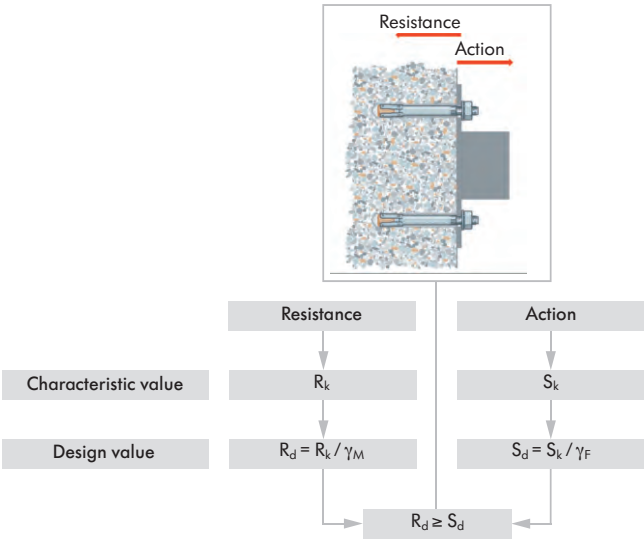


Figure 8.3: Flowchart for the design method with partial safety factors

The design method with partial safety factors is qualitatively shown in Figure 8.4.

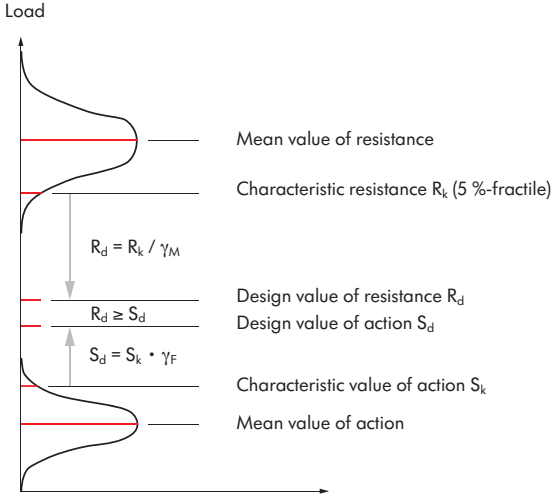

Load
Mean value of resistance
Characteristic resistance R_k (5 %-fractile)
$R_d = R_k / \gamma_M$
Design value of resistance R_d
$R_d \geq S_d$
Design value of action S_d
$S_d = S_k \cdot \gamma_F$
Characteristic value of action S_k
Mean value of action

Figure 8.4: Design concept using partial safety factors

The partial safety factors for the applied action differentiate between sustained loads (dead) and variable loads (live). The partial safety factors for the resistance account for the scatter of the material properties as well as the sensitivity to installation errors.

8.2 Design concepts for fastening to concrete

8.2.1 General

In existing European product approvals the design of fastenings in concrete is performed according to the design guideline in ETAG Annex C [38]. The ETAG design concept is divided into methods A, B, and C (Figure 8.5).

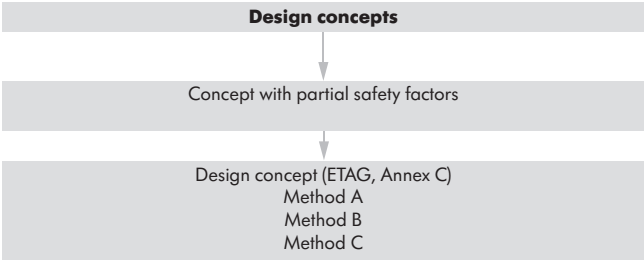


Figure 8.5: Design concepts and design methods in European technical approvals

In European technical approvals it is required that design is conducted by an engineer with knowledge in the field of reinforced concrete construction and fastening technique. Traceable calculations and construction drawings with the exact positions of the fastener must be prepared. Moreover, the position of the fastener must be put on record in the construction drawings.

In addition to determining the applied actions the engineer should check the minimum edge distances, member thickness, and fastener

spacing in order to select a suitable fastening system. After a fastening system is selected, the design can be concluded by calculating the characteristic resistances.

The characteristic resistance for concrete cone failure is mainly influenced by the condition of the base material (concrete). For fastener selection it must be checked if the concrete in the region of the fastening is cracked or non-cracked (see Section 2.2.5).

In general, the engineer should assume cracked concrete. Non-cracked concrete can be assumed only in special cases when it is shown that the concrete is non-cracked along the whole embedment depth of the fastener. This proof is fulfilled when Equation (8.1) is met.

$\sigma_L + \sigma_R \leq 0$		(8.1)
σ_L	Stresses in the surrounding concrete due to external actions (including fastener load)	
σ_R	Stresses in the surrounding concrete due to internal restraints (e.g. shrinkage) or due to external restraints (e.g. displacements of supports or temperature restraints) If no detailed calculation is performed, σ_R can be assumed as 3 N/mm².	

The stresses σ_L and σ_R must be calculated assuming non-cracked concrete. For members that transfer loads in two directions (e.g. slabs and walls), Equation (8.1) must be fulfilled in both directions.

According to Equation (8.1) fastenings located in walls are normally situated in cracked concrete because the loads applied to the fasteners cause tension stresses that cannot be overcome by compression stresses in the wall.

If Equation (8.1) is not satisfied fastening systems for cracked concrete have to be used.

8.2.2 Design using the ETAG design guideline ([3], [4])

8.2.2.1 General

The design guideline in ETAG Annex C differentiates between three different methods: A, B, and C (Figure 8.6). Design according to method A offers the most flexibility of the three methods and therefore the fastening system can be designed to its full potential. A comparison of the three different methods with their essential characteristics is given in Figure 8.6.

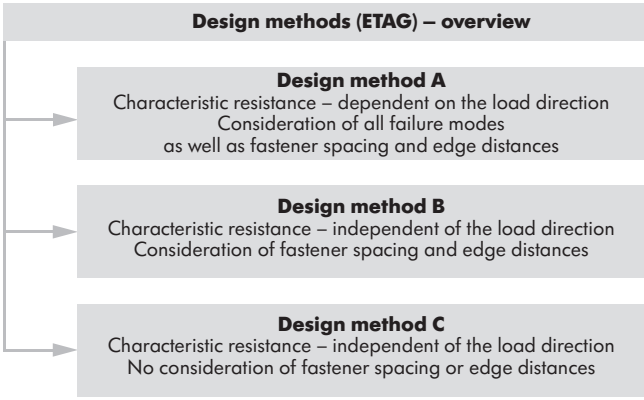

Design methods (ETAG) – overview
Design method A
Characteristic resistance – dependent on the load direction
Consideration of all failure modes
as well as fastener spacing and edge distances
Design method B
Characteristic resistance – independent of the load direction
Consideration of fastener spacing and edge distances
Design method C
Characteristic resistance – independent of the load direction
No consideration of fastener spacing or edge distances

Figure 8.6: Characterization of the design methods A, B, and C in the ETAG design guideline

8.2.2.2 Design method A

Design according to method A is based on the design concept with partial safety factors (see Section 8.1.2). The proof of the bearing capacity is performed using Equation (8.2).

$S_d \leq R_d$		(8.2)
S_d	Design value of the action	
R_d	Design value of the resistance	

The characteristic resistance of a fastening system calculated using the design method A is dependent on the load direction and all possible failure modes. The actions applied to the fastening must be smaller than or equal to the characteristic resistances for all failure modes (Figure 8.7). If this proof is satisfied the fastening is considered sufficiently safe.

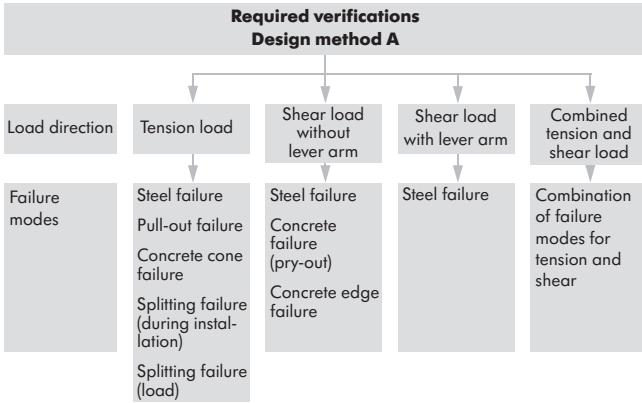


Figure 8.7: Required verifications for design method A

The design value for the action corresponds to the applied action multiplied by the partial safety factor for the action. In a fastener group the fastener forces are calculated from the external forces (axial force, shear force, bending, and torsion) using elasticity theory assuming equal stiffness for all fasteners of the group. This assumption requires that the fixture has sufficient stiffness. For combined tension and shear loads, the load is divided into an axial and a shear component.

The design value of the resistance is calculated from the characteristic resistance divided by the partial safety factor for the material resistance. The characteristic resistances are given in the product approvals for different failure modes (tension: Steel failure, pull-out; shear: Steel failure).

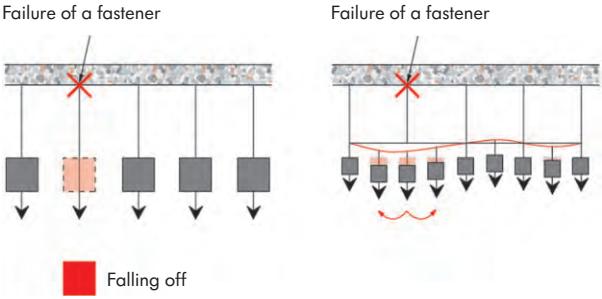
For the concrete failure modes under tension or shear loading (tension: Concrete cone failure, splitting; shear: Concrete edge failure, pry-out) the characteristic resistances are calculated using a general design method known as the CC-Method (CC = concrete capacity). The influence of edge distances, fastener spacing, and member thickness is accounted for in this method. The compressive strength of the concrete is taken into account as well.

The minimum design value of the resistance for the different failure modes in one direction is decisive for the design. In eccentrically loaded fastener groups where steel failure or pull-out failure controls the design under tension load as well as for steel failure under shear load the fastener with the largest load is decisive.

8.2.2.3 Plastic anchors with European technical approval

Area of application

For plastic anchors with European Technical Approval (ETA) fastenings with multiple anchorage points of so-called non load-bearing systems are possible. In general, non load-bearing system means that no parts of the load-bearing building construction collapse if the fastening fails but that 'only' the fastened fixture fails. This 'failure' can already lead to considerable damage to property or even to fatal injuries, if for example a suspended ceiling is affected. Therefore, fasteners with a technical approval have to be used for these kinds of applications.
In the case of a fastening with multiple anchorage points, a so-called redundant system, the fixture to be fastened has to be designed in a way that the load can be transferred to the adjacent fasteners if overly slip or failure of a fastener occur. This means that a load rearrangement to adjacent fasteners takes place (example b) compared to a fastening with single use (example a) and that the fastened fixture cannot fall off due to the failure of a fastener, for example caused by development of cracks in the concrete.

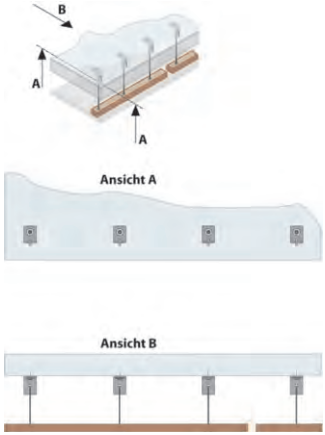


a) Single use:
Failure of the fastener

b) Multiple use:
Failure of the system

Figure 8.8: a) Single use *b) Redundant system*

Having a redundant system means that at least three anchor plates or ceiling hanger per element of the suspended substructure are necessary. As a result, load rearrangement to at least one adjacent fastener without failure of the fastened system is possible if one of the fasteners fails. In this case, the substructure must be stiff enough to transfer the loads and keep the deformations low (example b).



Example for a redundant system:
At least three or more fasteners per anchor plate or ceiling hanger

and

at least one or more fasteners per anchor plate or ceiling hanger necessary

Figure 8.9: Fastenings of suspended ceilings in safety-relevant areas are now possible with modern plastic anchors

Base materials

The classification of the base materials in the ETA's for plastic anchors is made in so-called use categories. Concrete equals the use category (a), solid masonry unit (b), perforated masonry unit (c), and autoclaved aerated concrete the use category (d). A combination of these use categories is also possible. The Würth plastic anchor W-UR has a European technical approval for all of these use categories. Every stone that meets the requirements according to EN 771 can be integrated in the approval. The characteristic loads of the ETA's for plastic anchors, however, are only valid for the stones mentioned in the approval. Exceptions are possible when it comes to dimensions and compressive strength. The loads for the respective stones are also valid for the tested stone with a higher compressive strength or with bigger dimensions.

Figure 8.10: Würth W-UR 10, universal plastic anchor approved for all use categories

9.1 Products with safety relevance

In general, it has to be distinguished between safety-relevant products, which are products where failure would compromise the stability of the structure, cause risk to human life, and/or lead to considerable economic consequences, and products where safety and economic aspects are of minor importance. An example of a fastening that is not safety-relevant is one for the fixture of paintings on a wall (assuming an inexpensive painting). For this kind of application no approvals are needed.

Provisions are needed for the use of building products in applications where safety is important. The characteristics, form, and use of building products must be stated in technical provisions, e.g. product standards. Examples of building products regulated by product standards in Europe are screws, nuts, precast concrete products such as concrete paving stones, and Portland cement.

In construction practice, however, building products are also used that differ from standards or technical specifications or where no generally acknowledged technical provisions exist. This is often the case for products where the individual or collective influences of the different factors governing their load-bearing behaviour are not yet sufficiently known. These products are designated as non-regulated building products. With a so-called 'proof of use' non-regulated building products can, however, also be applied for safety-relevant applications.

9.2 Post-installed fasteners

Post-installed fasteners belong to the category of non-regulated building products since the field of fastening technology still indicates huge potential for innovation and is far from being completely investigated. The documentation of designated purpose as a building product is given by a national approval or a European Technical

Approval (ETA) released by an authorized approval body such as BBA (Great-Britain), CSTB (France), or DIBt (Germany). The applicability of a product for its intended use according to a national or European approval must be demonstrated by experimental investigations. First, the proper functioning of a fastener under the possible conditions which can commonly occur during construction (installation procedure, condition of the concrete or masonry serving as base material) is investigated. Then the product reliability with regard to the influence of the different factors on the load-bearing and long-term stability is assessed. Finally, experiments are conducted to define the conditions of use for the fastener, i.e. its design resistance in cracked and non-cracked concrete.

Approvals, areas of application	ETA[1)]
Non-cracked concrete	x
Non-cracked concrete, light suspended ceilings	x
Cracked and non-cracked concrete	x
Autoclaved aerated concrete	x
Fastening of light suspended ceilings	x
Fastening of composite heat insulation systems	x
Plastic anchors for multiple use	x
Fastenings in masonry with injection anchors	x

[1)] European Technical Approval

Table 9.1: Examples of applications covered by ETA's

In Table 9.1 some examples of applications for which ETA approvals exist are summarized.

The variety in the fields of application indicates that it is not sufficient to simply select any fastener with an approval covering a safety-relevant application. The intended use for the fastener must exactly match with its defined approval.
The use of fasteners for single applications that are not covered by a technical approval can be made possible by an approval in individual cases. In order to do this it is necessary to make an application to the highest legal board of construction of the county where the building object is situated. The board will examine the fastener with regard to the designated application and, if the examination was positive, will approve the fastener for this specific application.
The compliance of a product with a standard or a technical approval is confirmed by CE conformity mark. It is stated on the packaging or the package insert of the anchor.

9.3 European harmonization

With the merging of Europe, national product approvals and standards are being increasingly replaced by European provisions. The national provisions will disappear in many fields of construction technology after a transition phase. This process is intended to reduce trade barriers between states of the European Community. For this reason the European Construction Products Directive (CPD) [22], which regulates the free merchandise of building products within the EC was created. The CPD (will be replaced completely by the Construction Products Regulation CPR by July 1, 2013) ensures that only acceptable products are marketed and used. CPD-regulated products must meet following essential requirements:

- Mechanical resistance and stability,
- safety in the case of fire,
- hygiene, health, and the environment,
- safety in use,
- protection against noise,
- energy economy and heat retention.

According to the Construction Products Directive building products such as fasteners may be marketed Europe-wide if they are usable and the conformity of the product with the CPD is certified. This is indicated by the CE-mark on the product. Fasteners with a European Technical Approval (ETA) automatically fulfil the usability requirement. If an ETA is existent it is only allowed to issue national approvals for new products for a limited transition period.

Presently, European Technical Approval Guidelines and ETA's exist for mechanical fastening systems such as torque-controlled expansion anchors, drop-in anchors, or undercut anchors as well as for chemical fastening systems such as bonded anchors, bonded-expansion anchors and for post-installed rebars. Fastening systems for the transfer of small loads in redundant systems (fasteners for suspended ceilings and plastic anchors) are also covered.

For mechanical fastening systems the transition period from national to European approvals has already ended in July 2002. This means that a manufacturer of a new mechanical fastener can only apply for a European Technical Approval.

National approvals that are only valid in their country of origin are increasingly replaced by ETA's. ETA's are accepted in all of Europe, represent the state-of-the-art, and the ETA-approved products can be marketed throughout Europe.

9.4 Contents of a fastener approval

The content of the product approval documents follows basically the same structure, independent of whether it is issued by the BBA, CSTB, DIBt, or another European approval authority. The product approval contains the following information:

- General conditions
  Legal basis, task, use, and effectiveness of the approval

- Special conditions
  - Objective of the approval, description of the fastener and its field of application
  - Provisions for the fastener
    - Features, material properties, and composition
    - Production, packaging, transport, storage, and marking
    - Conformity, proof of conformity, CE-marking
  - Conditions for design
  - Conditions for installation
  - Conditions for use and maintenance

In addition, it should be mentioned that the design method to be used for a certain fastener depends on the type and number of tests performed during its approval process. The relation between the testing and design method is exemplary shown in Table 9.2 for the tests according to the European Technical Approval Guideline. Options 1-6 are for various fields of application in cracked and non-cracked concrete. Fasteners that were assessed according to options 7-12 are only allowed for use in non-cracked concrete. As the option number decreases, the fields of application increase and a more detailed and economical design of a fastening can be carried out. The optimum represents a fastener design according to design method A in Annex C of the European Technical Approval Guideline (ETAG). Accordingly,

fasteners with an approval according to option 1 undergo the most comprehensive tests with the widest field of application. The smallest field of application is obtained for fasteners tested according to option 12. It is not allowed to use a fastener for another field of application than indicated by the corresponding approval.

Option	Cracked and non-cracked	Only non-cracked	Only C20/25	C20/25 to C50/60	F_{RK} valid for all load directions	F_{RK} dependent on load direction	c_{cr}	s_{cr}	c_{min}	s_{min}	Design method according to Annex C
1	X			X		X	X	X	X	X	A
2	X		X			X	X	X	X	X	
3	X			X	X		X	X	X	X	B
4	X		X		X		X	X	X	X	
5	X			X	X		X	X			C
6	X		X		X		X	X			
7		X		X		X	X	X	X	X	A
8		X	X			X	X	X	X	X	
9		X		X	X		X	X	X	X	B
10		X	X		X		X	X	X	X	
11		X		X	X		X	X			C
12		X	X		X		X	X			

Table 9.2: Testing method and design procedure after ETAG 001 for fasteners in concrete

9.5 Use of product approvals in fastening technology

The procedure shown in Figure 9.1 is valid for the use of fastenings with post-installed fasteners. Fastenings not covered by the requirements of the Construction Products Directive or which are not safety-relevant can be designed according to the manufacturer's recommendations.

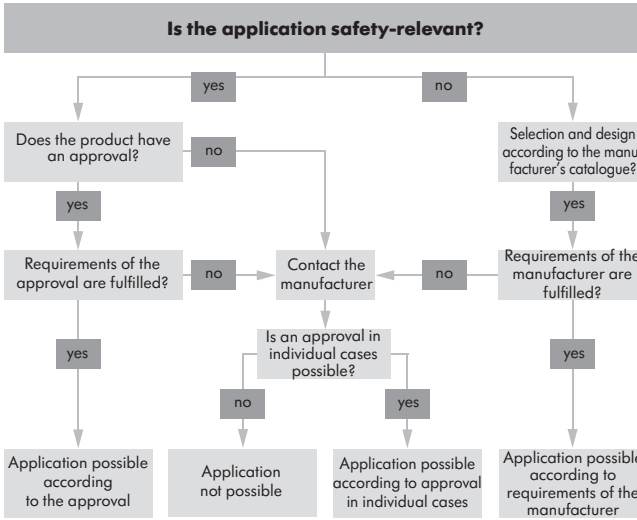


Figure 9.1: Procedure for using fasteners according to regulations

10. Inappropriate application of fastenings and resulting damages

A fastening should be both secure and durable. This goal can only be achieved when the manufacturer and user work together (Figure 10.1). The manufacturer's job is to develop secure, practical, and economical fastening systems. The proper functioning of these fastening systems is validated during the approval process and their quality is continuously monitored by both the internal quality management of the company as well as by independent organizations. The best fastening system, however, cannot guarantee a secure and durable fastening without proper planning, design, and installation by the user.

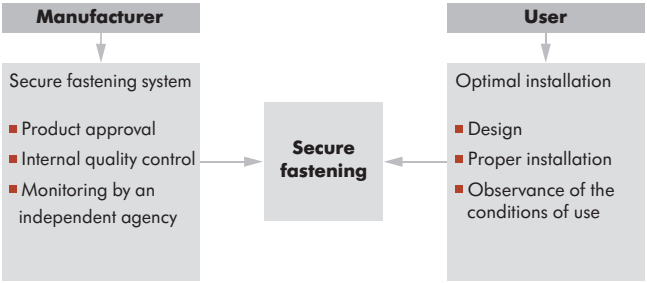


Figure 10.1: Interaction between manufacturer and user to guarantee a secure fastening

Although secure fastening systems are available, cases of damages are frequently observed. Detailed investigations [23] show that damages are caused in most cases by human error. The cost of planning and design of fastenings normally amounts to only a small part of the total cost of a building. Damages resulting from poorly planned or inappropriately used fastenings, however, can be very costly and can endanger human life.

The execution of a fastening normally consists of two different stages (Figure 10.2). In the first stage, an engineer selects a suitable fastener and performs the design of the fastening. This requires fundamental knowledge about fastenings in order to account for the main influencing factors.
In the second stage, the installation, the installer requires basic knowledge about the fastener he is installing and the parameters that influence the installation.

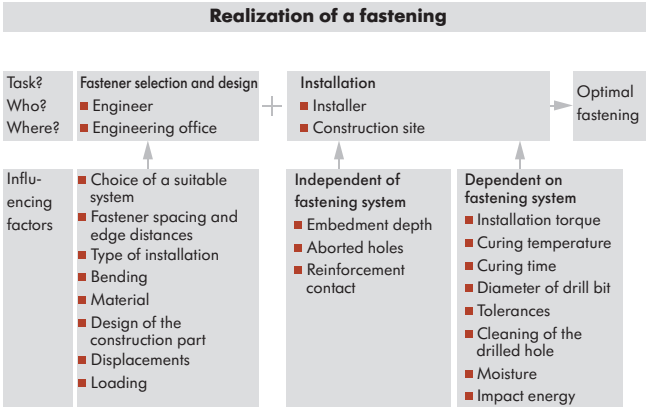


Figure 10.2: Different stages in the execution of a fastening and essential influencing parameters

Mistakes due to inadequate planning, improper installation, or unintended use of fasteners can be observed frequently in practice. Some examples of failed fastenings separated into the areas of planning, installation, and application are shown in Figure 10.3.

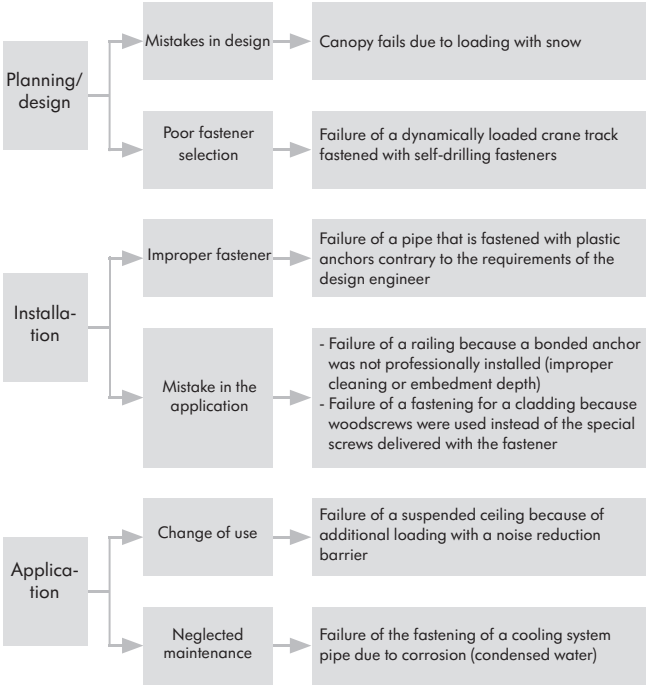

Planning/ design
Mistakes in design
Canopy fails due to loading with snow
Poor fastener selection
Failure of a dynamically loaded crane track fastened with self-drilling fasteners
Installa-tion
Improper fastener
Failure of a pipe that is fastened with plastic anchors contrary to the requirements of the design engineer
Mistake in the application
- Failure of a railing because a bonded anchor was not professionally installed (improper cleaning or embedment depth)
- Failure of a fastening for a cladding because woodscrews were used instead of the special screws delivered with the fastener
Applica-tion
Change of use
Failure of a suspended ceiling because of additional loading with a noise reduction barrier
Neglected maintenance
Failure of the fastening of a cooling system pipe due to corrosion (condensed water)

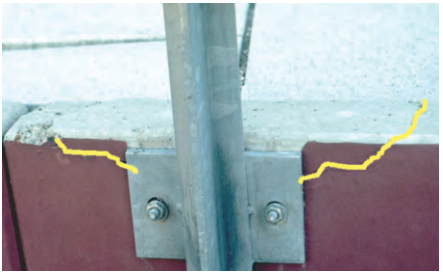
Figure 10.3: Examples of mistakes in planning/design, installation, and application [23]

Mistakes in planning or installation can be divided into two categories: Obvious and hidden defects. Failures can have legal as well as economic consequences. Typical defects are summarized in Table 10.1. Figure 10.4 shows photographs of damages.

Obvious defects	Hidden defects
■ Splitting or spalling in the base material ■ Aborted holes ■ Imminent failures (large displacements) ■ Incorrect material, e.g. exterior space application	■ Incorrect embedment depth ■ Improper fastener choice ■ Immediate loading (bonded anchors) ■ Incorrect installation torque ■ Cut reinforcement ■ Insufficient drill hole cleaning ■ Incorrect type of drilling (perforated material) ■ Insufficient expansion

Table 10.1: Obvious and hidden defects in the installation of fastenings

a) Inadequate edge distance



b) Too high load

c) A failure waiting to happen?

Figure 10.4: Examples of damages and inappropriate applications of fastenings

To determine the most economic fasteners for an application it is not sufficient to simply compare prices between different products and manufacturers. One must also look at all of the costs associated with planning and installing the fastening. These costs are summarized in a so-called cost benefit analysis. The primary cost factors are summarized in Table 11.1 and explained briefly below. The summarized costs are not necessarily complete for all applications. Depending on the specific fastening application further conditions may govern the right decision.

The costs for the fastener installation are influenced by
- the price of the fastener,
- the required drilling machine,
- the drilling tool (appropriate application of special drill bits),
- diameter and depth of the drilled hole ➞ drilling time,
- the waiting period up to the beginning of laoding (bonded anchors), and
- the checks necessary to ensure correct installation.

Furthermore, attention must be paid to the effort associated with installation like
- delivery time of the fasteners, drilling tools, etc.,
- storage (cooling of chemical anchor components),
- necessary times, e.g. for the transport between location and storage and installation of the fastener, and
- setup times, e.g. use of scaffolds, elevating platforms, ladders.

Additionally, the performance of the fasteners as well as advantages with regard to availability, billing, and ease of installation should be taken into consideration. Time differences of a few minutes per fixing point can add quickly and represent an essential factor in costs. Furthermore, one must keep in mind the possible acquisition costs of special drilling tools (stop drills) which are considerably higher than for

normal drill bits and which, in many cases, are not universally applicable.

Fastener selection should be primarily based on creating a safe and durable fastening. Subsequent repair or retrofit is almost always difficult and time-consuming. It represents a considerable cost factor not included in the initial cost analysis. Therefore, the most important points for the fastener selection are repeated here.

- Environmental conditions: Temperature, moisture, presence of aggressive agents
- Base material: Type (concrete, masonry), condition (cracked, non-cracked), and strength
- Action: Magnitude, type, and direction

[1] Erection times must be considered, e.g. for a scaffold, ladder, etc., in the case of chemical fasteners: Hardening time

[2] For example, installation tools, torque wrench, special drill bit, cleaning brush, etc.

Table 11.1: Parameters influencing the costs of a fastening

Item	Line			Option 1	Option 2
Fastener	1	Designation			
	2	Number of fasteners			
	3	Cost per fastener	€		
	4	Availability			
	5	Line 2 x line 3	€		
Storage	6	Cost of special storage (required temperature, ventilation), e.g. chemical products	€		
Drill bit and rotary hammer	7	Wear on rotary hammer			
	8	Drill bit diameter			
	9	Drilled hole depth			
	10	Number of drilled holes performed by drill bit			
	11	Number of needed drill bits			
	12	Cost of the drill bits	€		
	13	Line 11 x line 12	€		
Borehole	14	Time required per drilled hole including cleaning			
	15	Line 14 x hourly wage	€		
Installation	16[1)]	Time required per fastener for installation			
	17	Time for required checks, on-site tests			
	18	Line 16 + Line 17	€		
	19	Line 18 x hourly wage	€		
	20[2)]	Special installation tools	€		
	21	Line 19 + line 20	€		
Total	22	Line 5 + line 6 + line 13 + line 15 + line 21	€		
	23	Preferred option			
	24	Special location conditions to be considered			

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